Presented at:
Applied Modeling & Simulation (AMS) Seminar
NASA Ames Research Center
March, 12th 2015

Strategies for Modularization and Integration of OVERFLOW and FUN3D into CREATE™-AV Helios and its Applications

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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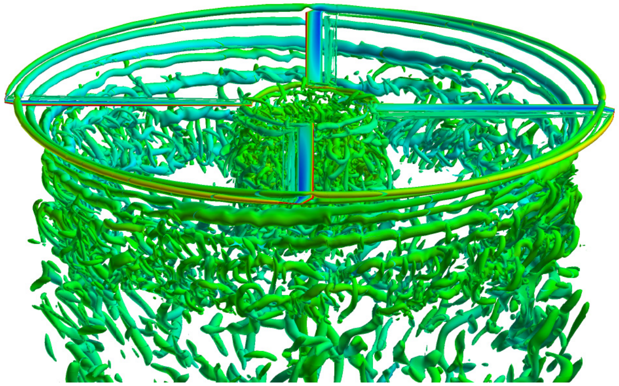
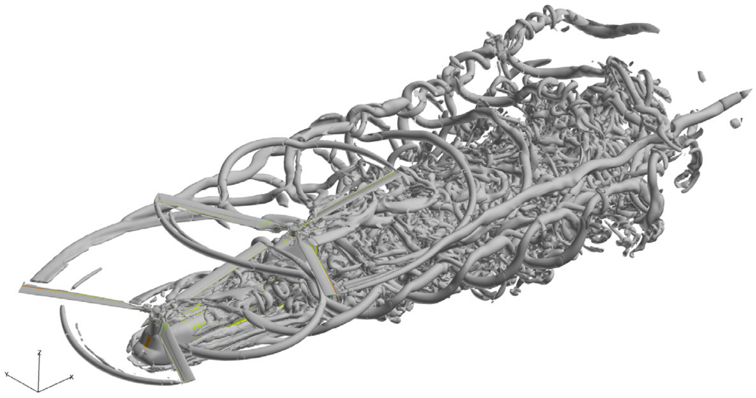
Outline

- Helios and its Architecture
- OVERFLOW Modularization and Integration



- Validation Example Cases
- FUN3D Modularization and Integration



- Summary and Concluding Remarks

CREATE™-AV Helios

- High-fidelity modeling and simulation to reduce risk, reduce cost, and enhance safety for new DoD aircraft acquisitions programs

Helios is being actively used to help make procurement decisions

- **Hover and cruise performance**
- **Hover download**
- **Interactional aerodynamics**

Joint Multi-Role Rotorcraft / Future Vertical Lift

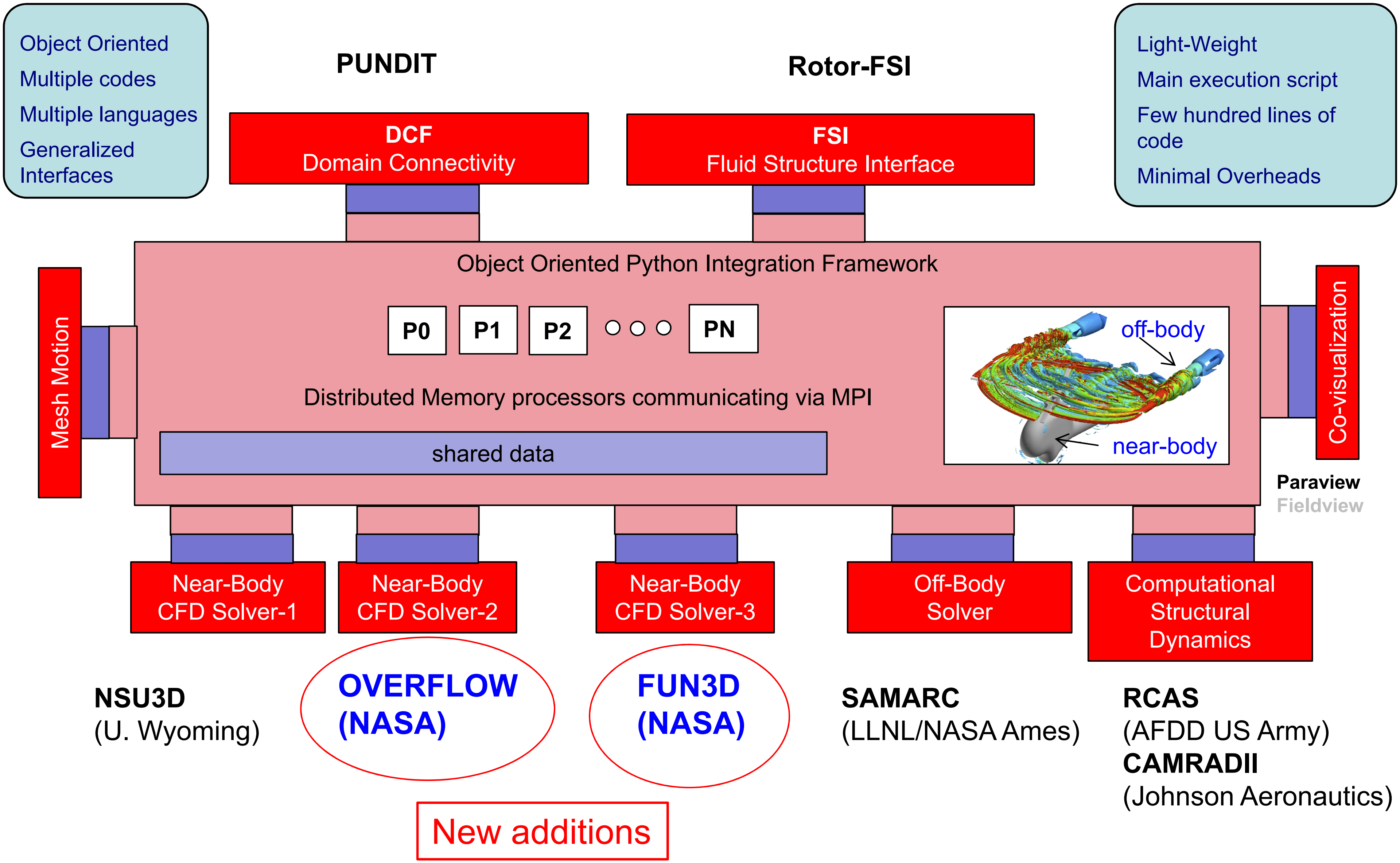
eometry

n

Best Software Practices

- ***Flexible***
- ***Extensible***
- ***Modular***

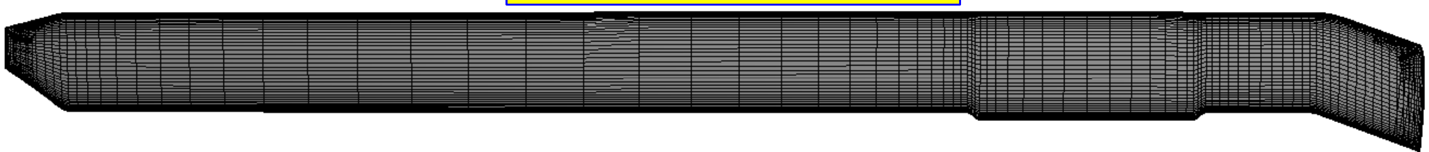
Helios Architecture



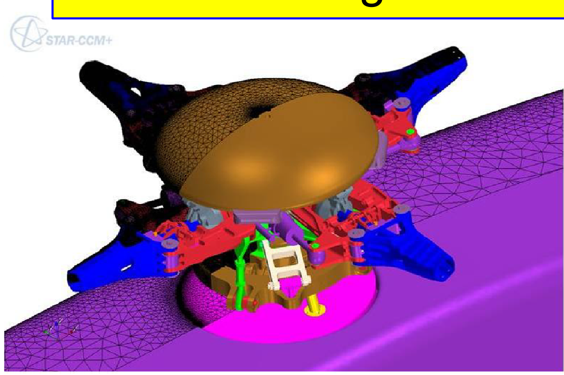
Why have the structured solver option?

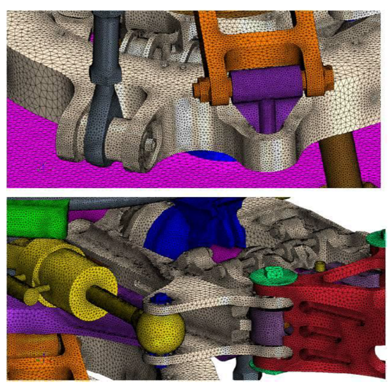
- Structured solvers are efficient, accurate (high-order), easy to grid for simple geometries (blades)…in-house tools exist to automate grid generation!
- Unstructured solvers offer rapid turnaround for complex geometries
- Leverage from both for now! …while next generation high-order unstructured solvers (e.g. strands, Discontinuous Galerkin etc.) mature

UH-60A rotor blade

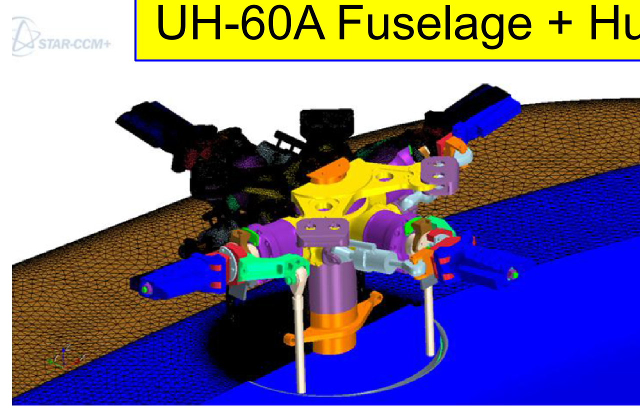


S-92A Fuselage + Hub





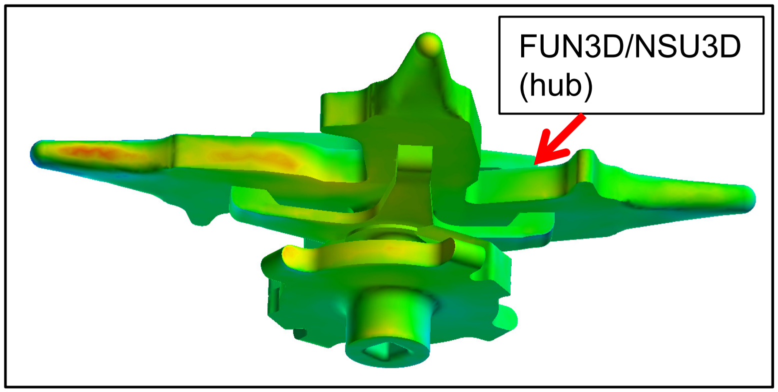
UH-60A Fuselage + Hub

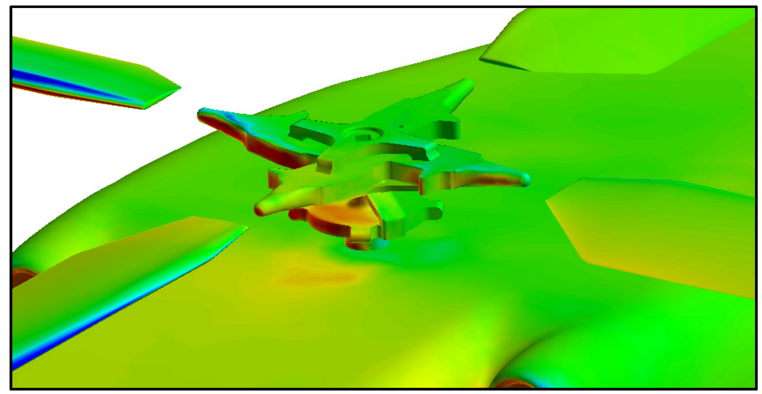


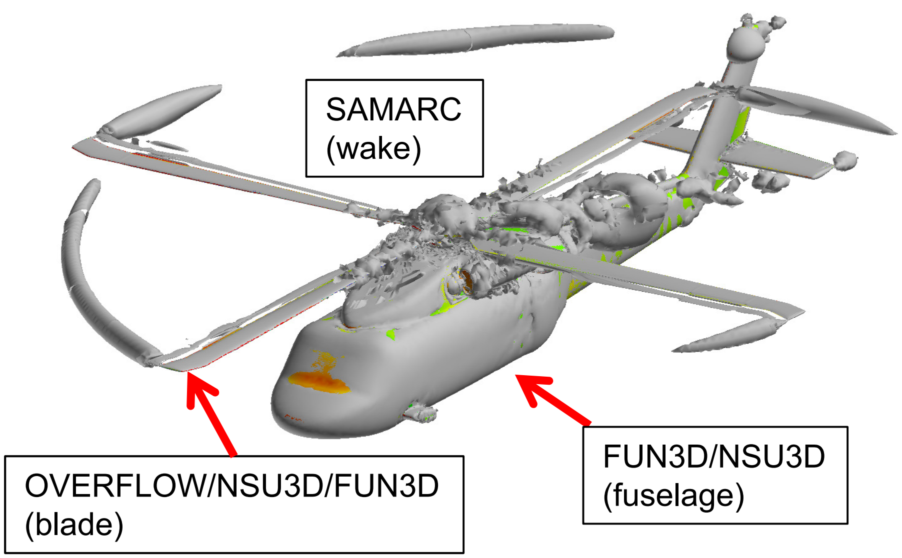
Ref: Dombroski et al, AHS Forum 2012

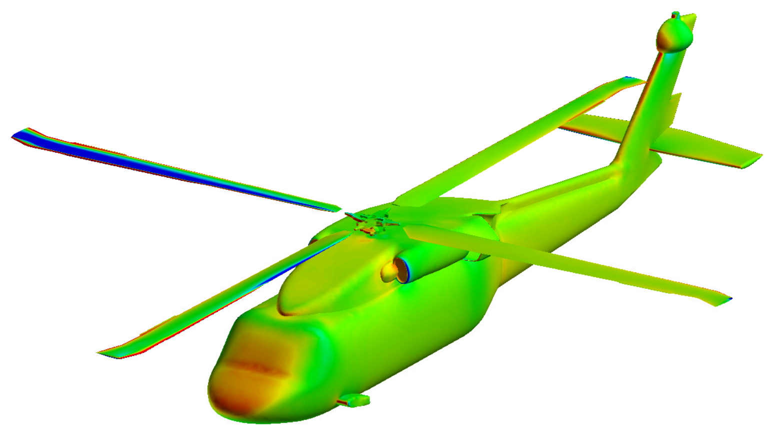
Helios Triple-mesh Approach

- ✓ **Structured/unstructured** **mesh solver for blades (simple configurations)**
- ✓ **Unstructured** **mesh solver for hub, fuselage (complex configurations)**
- ✓ **Cartesian** **adaptive mesh solver for off-body regions**





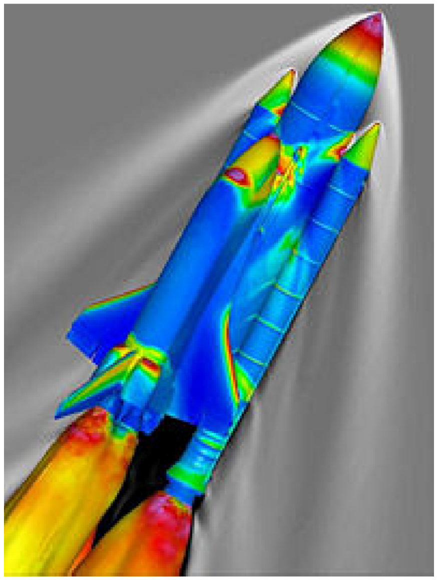




Notional hub geometry courtesy of Sikorsky
Fuselage geometry courtesy of NASA Langley

Why OVERFLOW?

- Overset structured grid solver
- Several key desirable features
  - Efficient (storage, domain decomposition, **3X-5X** speed-up over unstructured mesh solver)
  - Acceleration methods (line relaxation, multi-grid)
  - High-order schemes
  - Turbulence and transition modeling
  - Near-body grid adaptation



- Validated for a wide variety of rotorcraft problems
  - Rotor, fuselage, hub, flaps, coaxial rotor system
  - Coupling with CSD (computational structural dynamics)
  - Steady and maneuver flights
  - Dynamic stall
- Industry users are vested
  - Effort spent in mesh generation, validation, developing know-hows…
- Continuously being developed and supported

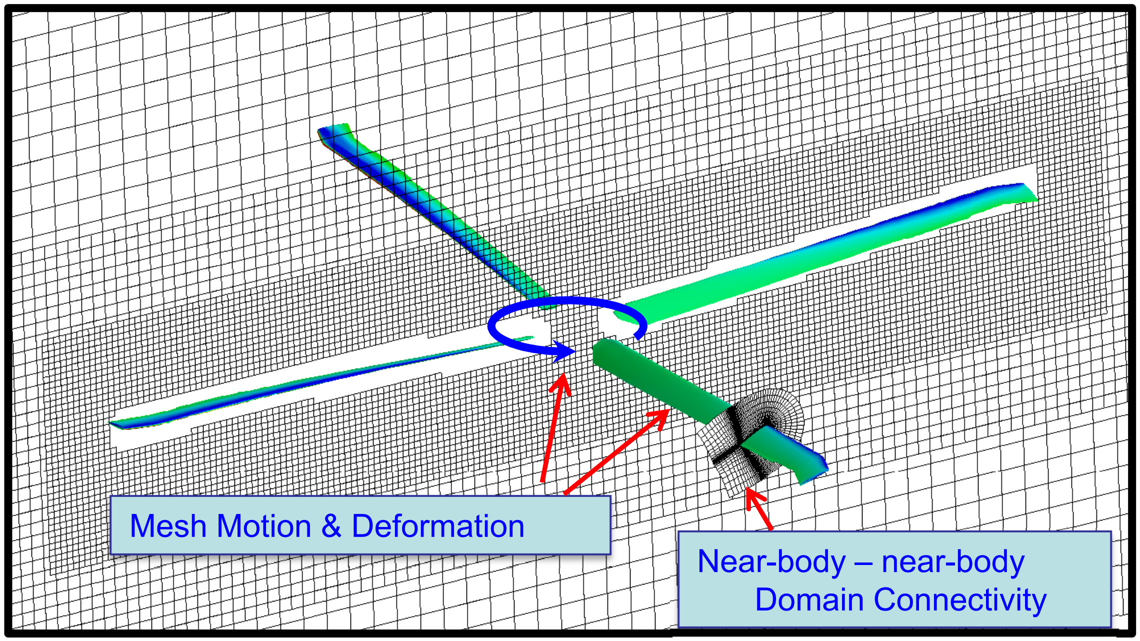
Modularized OVERFLOW

What is retained?

- ✓ Mesh Motion (GMP/XML) & Mesh Deformation
- ✓ Near-body Connectivity (viscous stencil repair)
- ✓ FOMOCO
- ✓ Parallel grid partitioning

What is not?

- ✗ Off-body region
- ✗ FSI
- ✗ File-based CFD/ CSD Coupling

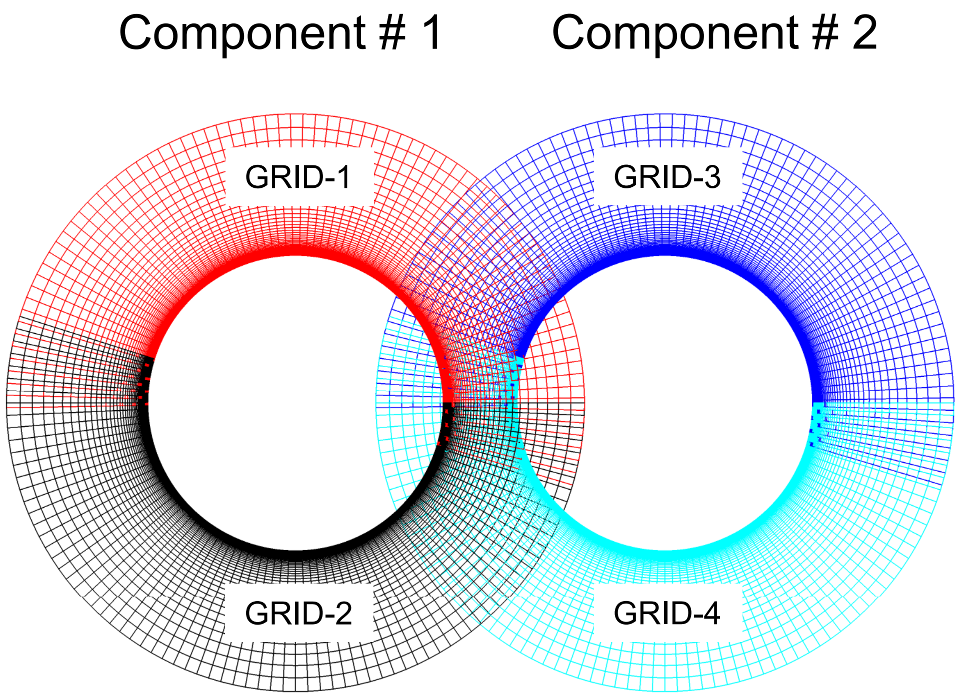


Helios modules used for:

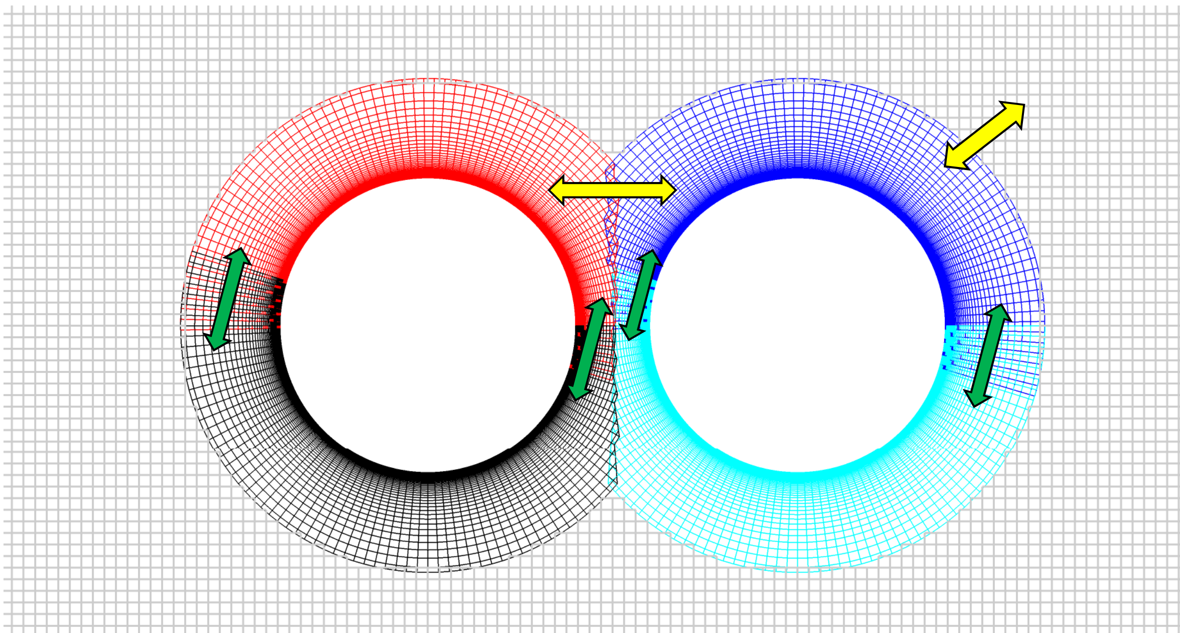
- Near-body – off-body domain connectivity
- Fluid Structure Interface (RCAS/CAMRADII/…)
- Adaptive Cartesian grids solution
- Unstructured grids solution
- Co-visualization

….

Helios-OVERFLOW Connectivity Strategy



Helios-OVERFLOW Connectivity Strategy



OVERFLOW COMMUNICATION

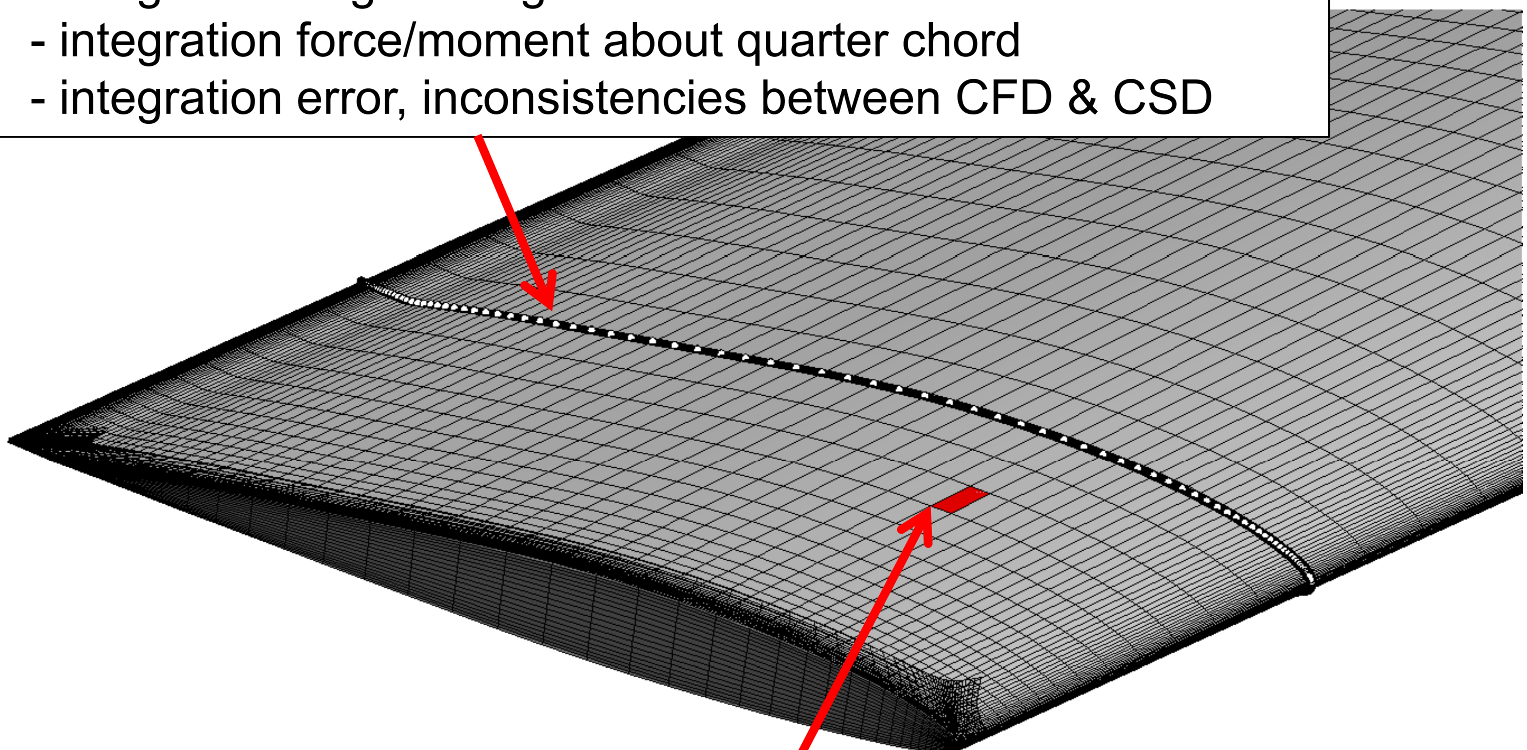
- Intra-component grid connectivity & communication

Helios COMMUNICATION

- Inter-component grid connectivity & communication
- Components (near-body) to off-body communication

Helios-OVERFLOW Fluid-Structure Interface

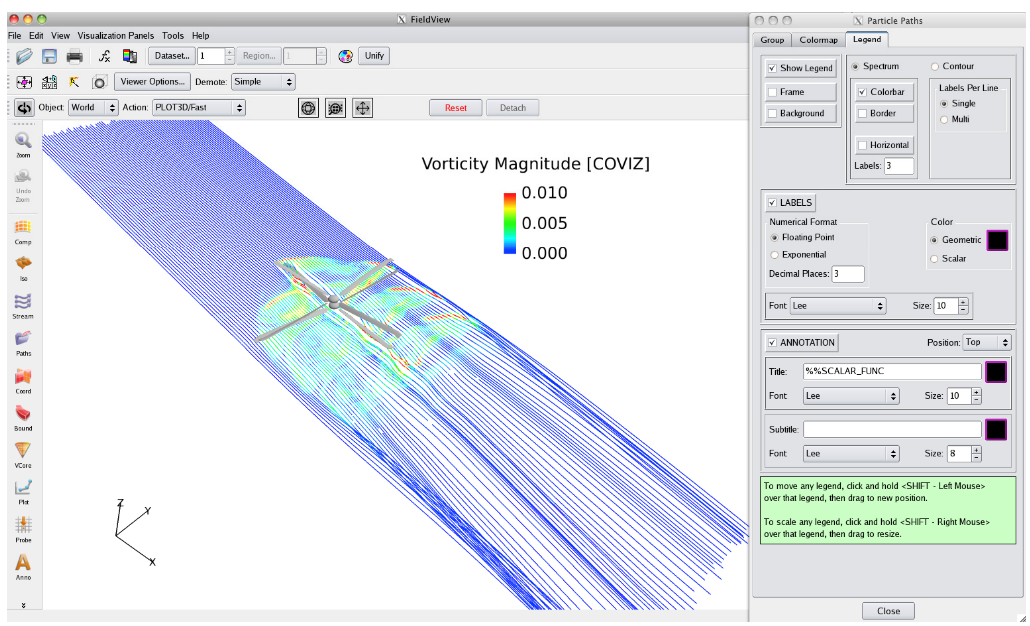
Traditional approach:
- integrate along blade grid line
- integration force/moment about quarter chord
- integration error, inconsistencies between CFD & CSD



New approach inherited from the Helios FSI module:
- accurate, conservative
  - integrate face-by-face on stitched FOMOCO surface
  - convert to 1-D beam forcing based on principle of virtual work
- applicable to large surface deformation and flapped rotor cases

On-the-fly Co-Visualization with Helios-OVERFLOW

- On-the-fly, parallel co-visualization
- Handy for large dataset simulation running on remote clusters
- Slices, iso-surface, streamlines, point/line/surf probes, particle trajectories
- User defined types

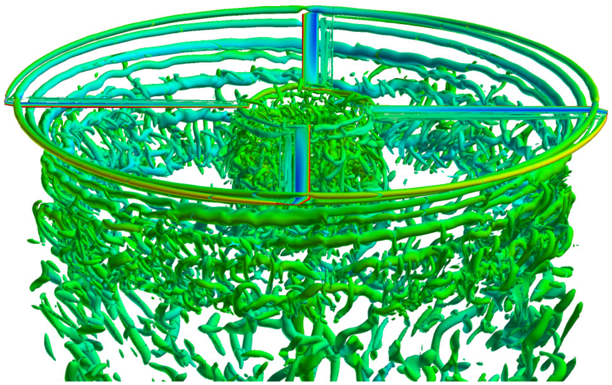


Helios-OVERFLOW Code Management Strategy

- **OVERFLOW**
  - **A single, common source code repository**
    - *make* – compiles standalone executable
    - *make library* – compiles the python version
    - code encapsulation using preprocessor (#ifdef PYTHON)
    - **Standard release (version 2.2j and higher) comes with the Helios "hooks"** (Thanks to Pieter Buning, NASA Langley)
- **Helios**
  - **A common python interface for NSU3D and OVERFLOW (and FUN3D)**

Validation Example Cases

1. Hover Predictions for the S-76 Rotor with Tip Shape Variation using **CREATE-AV Helios/OVERFLOW**

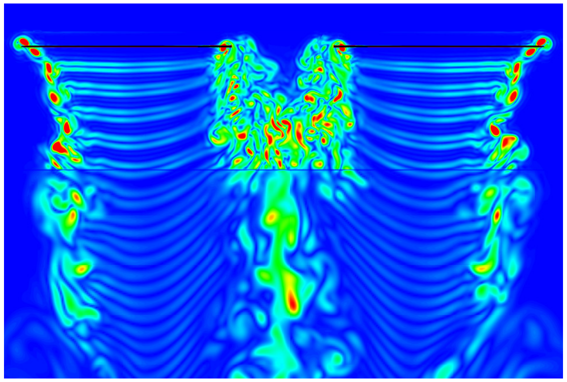


Presented at:

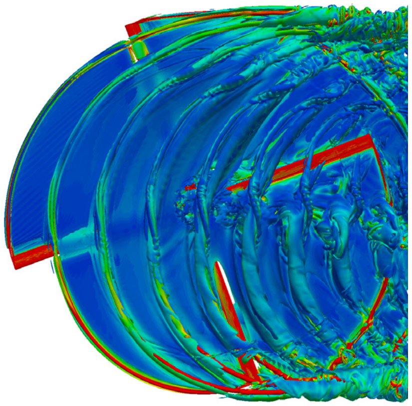
SCITECH 2015

Kissimmee, Florida
January 5-9, 2015

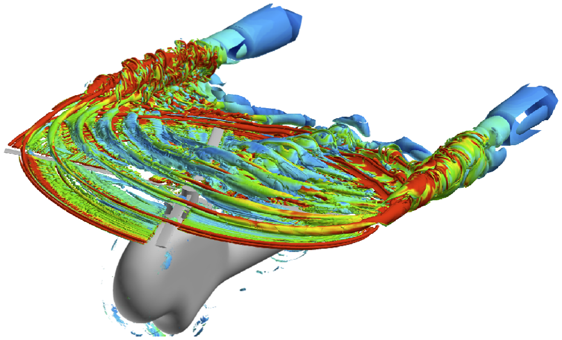
Paper: AIAA-2015-1244



2. **Helios Modular Multi-solver Approach for Efficient High-fidelity Simulation of the HART II Rotor**



Presented:
Fifth Decennial AHS Aeromechanics Specialists' Conference,
Jan 22–24 2014, San Francisco, California



CASE-I : S-76 Hover Prediction Workshop

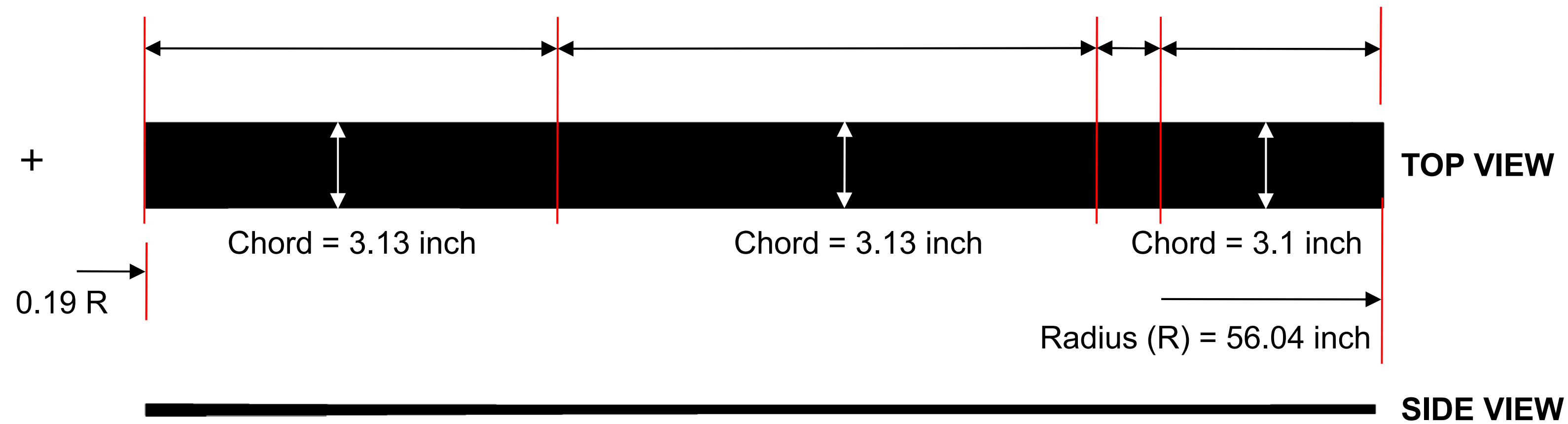
- Accurate hover prediction still a challenging problem
  - Affected by Reynolds number, Mach number, swirl flow, blade shape, vortical wake, test facility, etc.
  - High prediction accuracy expected from modern computational tools
    - 1 … b of thrust!)
  - Curren … ore)

GOALS:

- **Assess performance prediction accuracy of various tools using a common dataset**
- **Assess the blade airloads and wake geometry in addition to performance**

Tip Shapes

Rectangular



Swept-tapered

Swept-tapered-anhedral

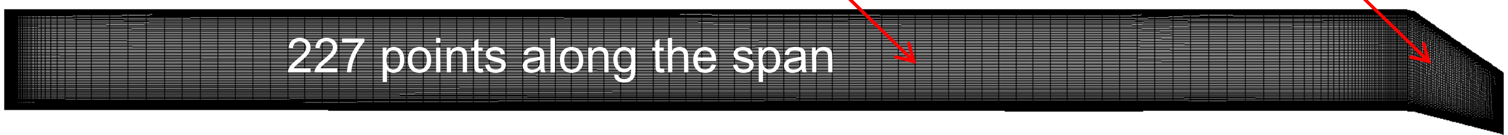
High Resolution OVERFLOW Blade Mesh

Spanwise spacing

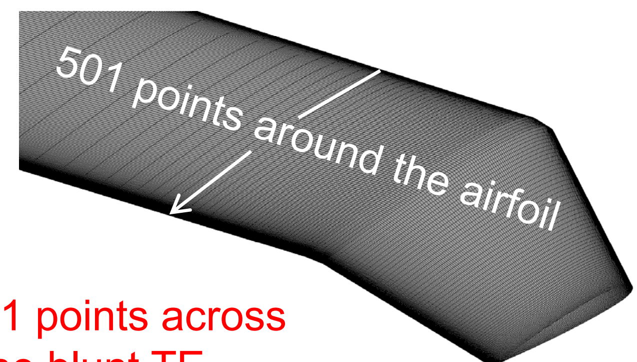
$\Delta R \approx 1\%\ R$

$\Delta R \approx 1.5\%\ c$

Clustering near the tip (~100 points)

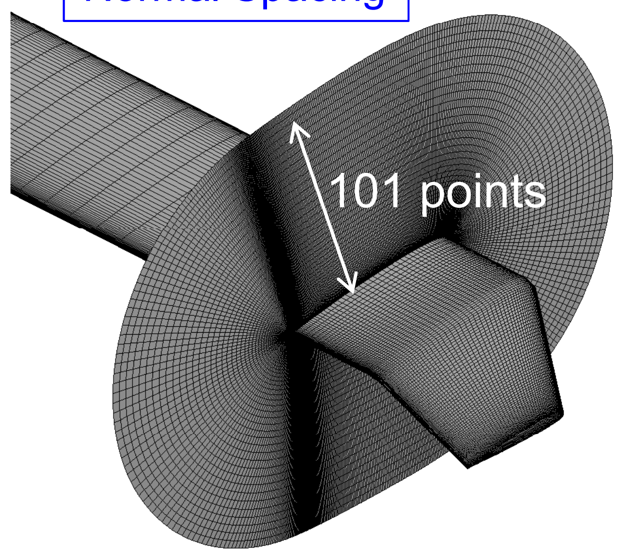


Chordwise Spacing



31 points across the blunt TE

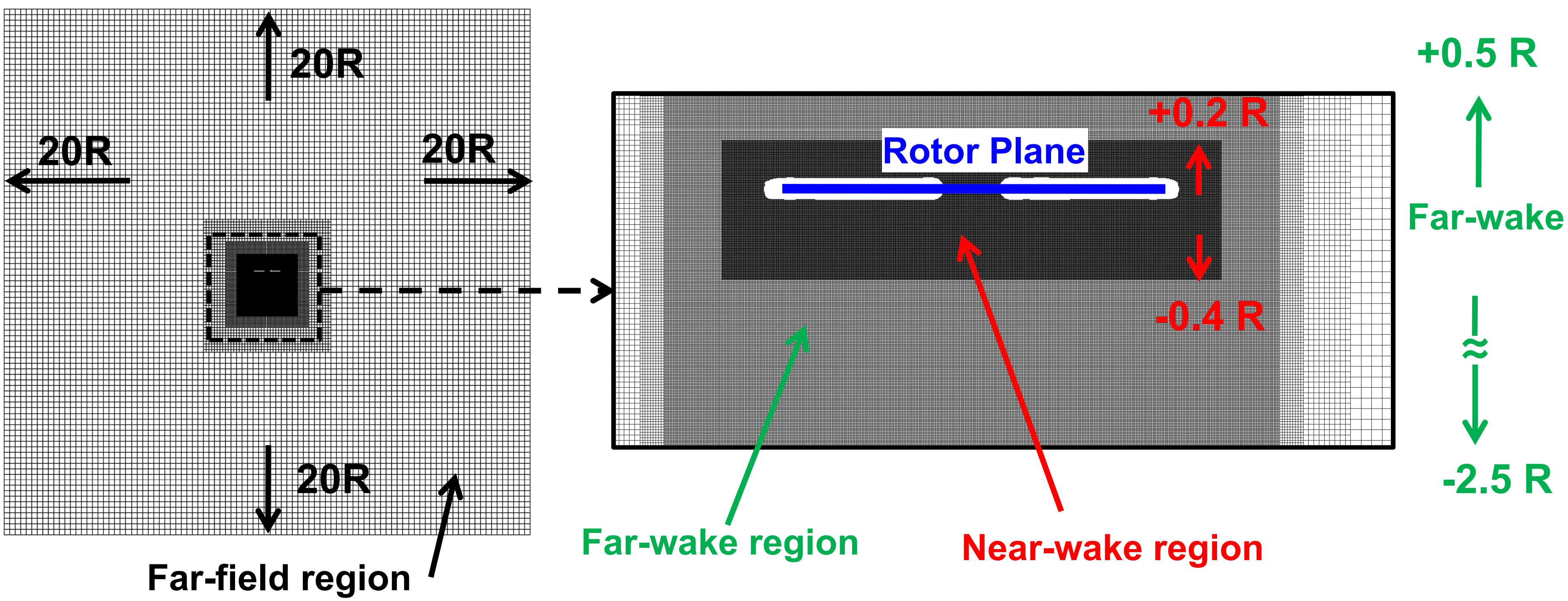
Normal Spacing



wall-normal spacing = y^+ of 0.5
outer boundary normal spacing = 4% c

~12 million points per blade

High Resolution SAMARC Wake Mesh



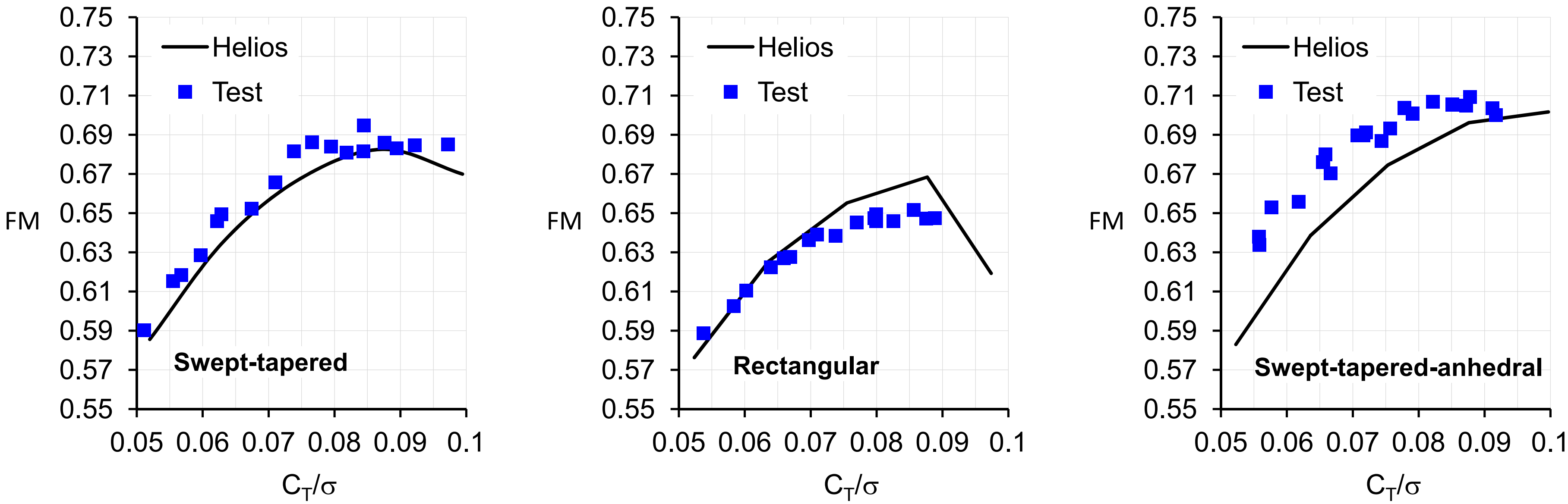
Wake Mesh (~400 million points):

ΔX = 5% chord in near-wake region

ΔX = 10% chord in far-wake region

Effect of Tip Shape Variation on Performance

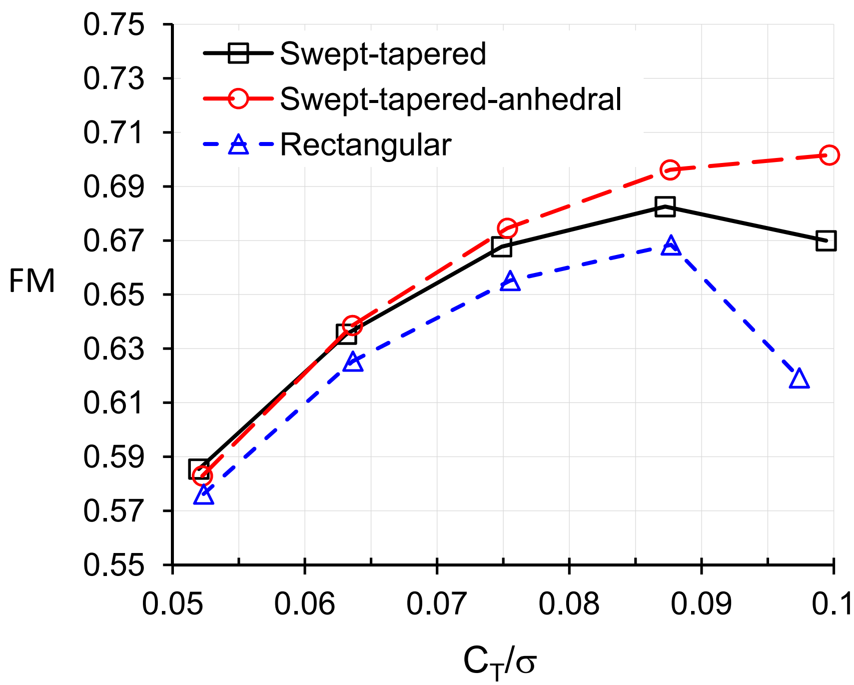
- Magnitudes differ – by up to 3 counts for anhedral tip at low thrust



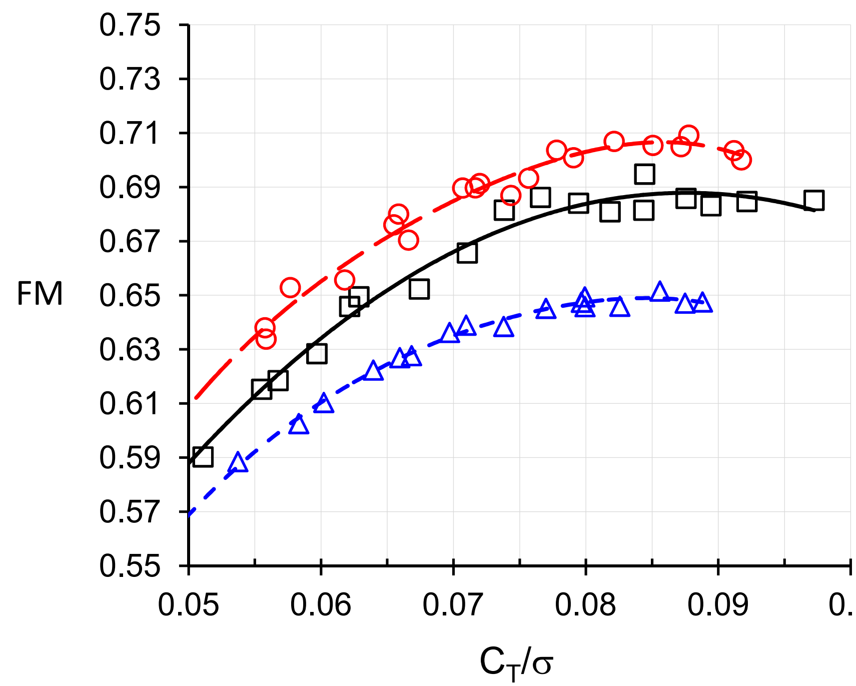
Discrepancy of up to 1.5, 2, and 3 counts for swept-tapered, rectangular, and swept-tapered-anhedral tip shapes, respectively. (1 count = 0.01 in figure of merit)

Tip Shape Variation Performance Trends

CFD Predictions

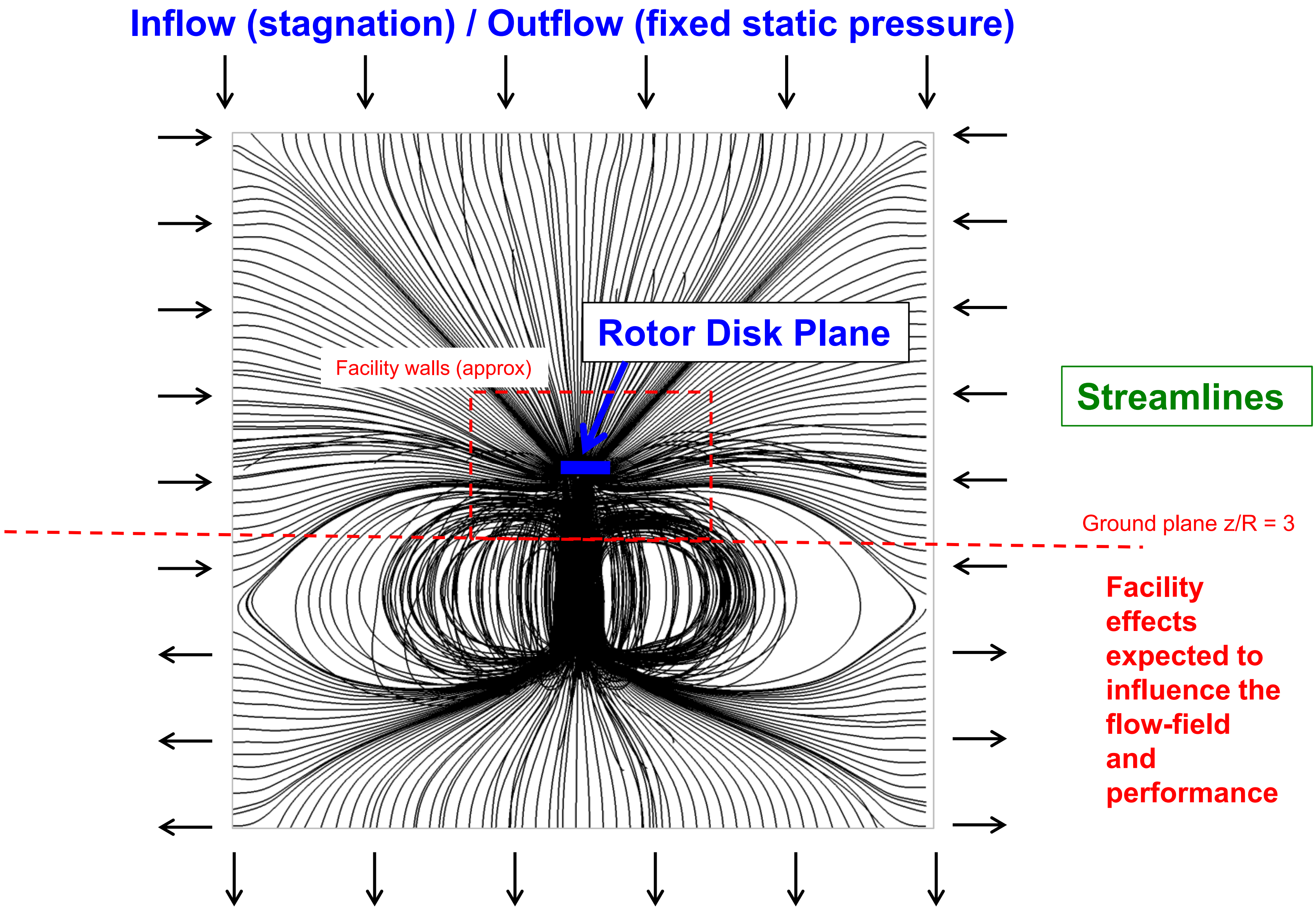


Wind-tunnel Measurements



Trends are captured well except for the anhedral tip at low thrust.

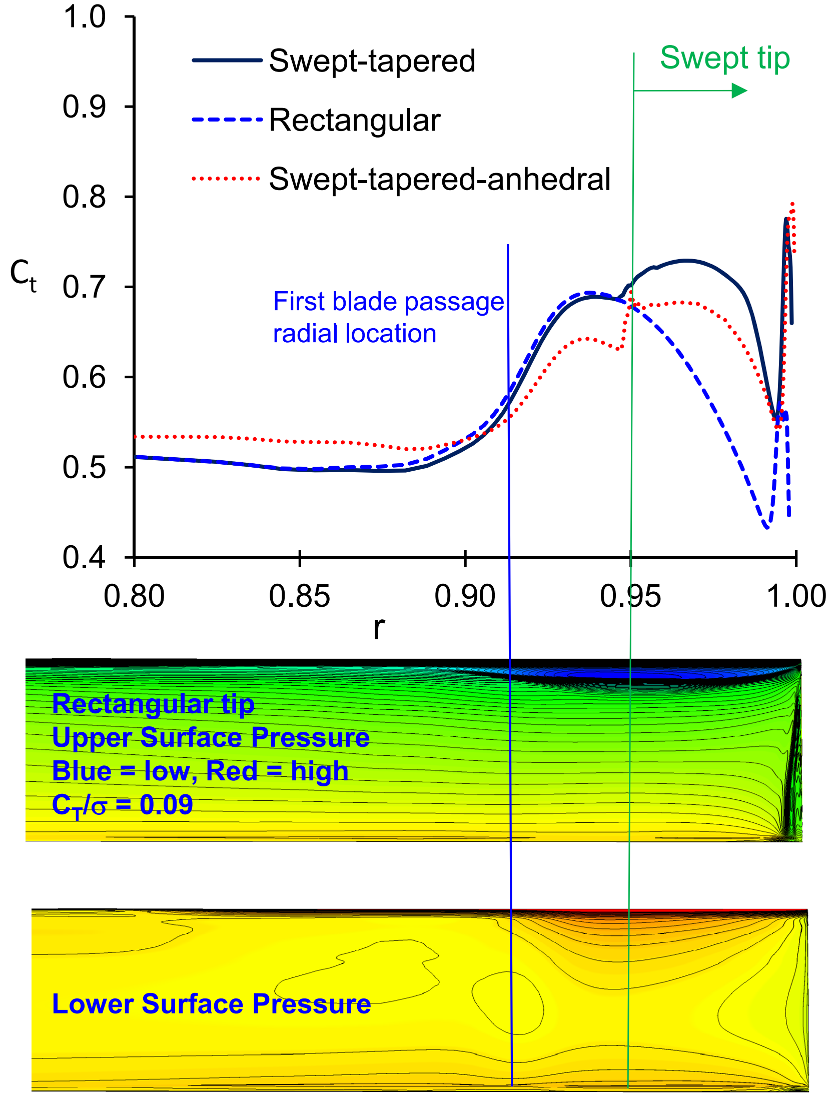
Facility Effects (in progress)



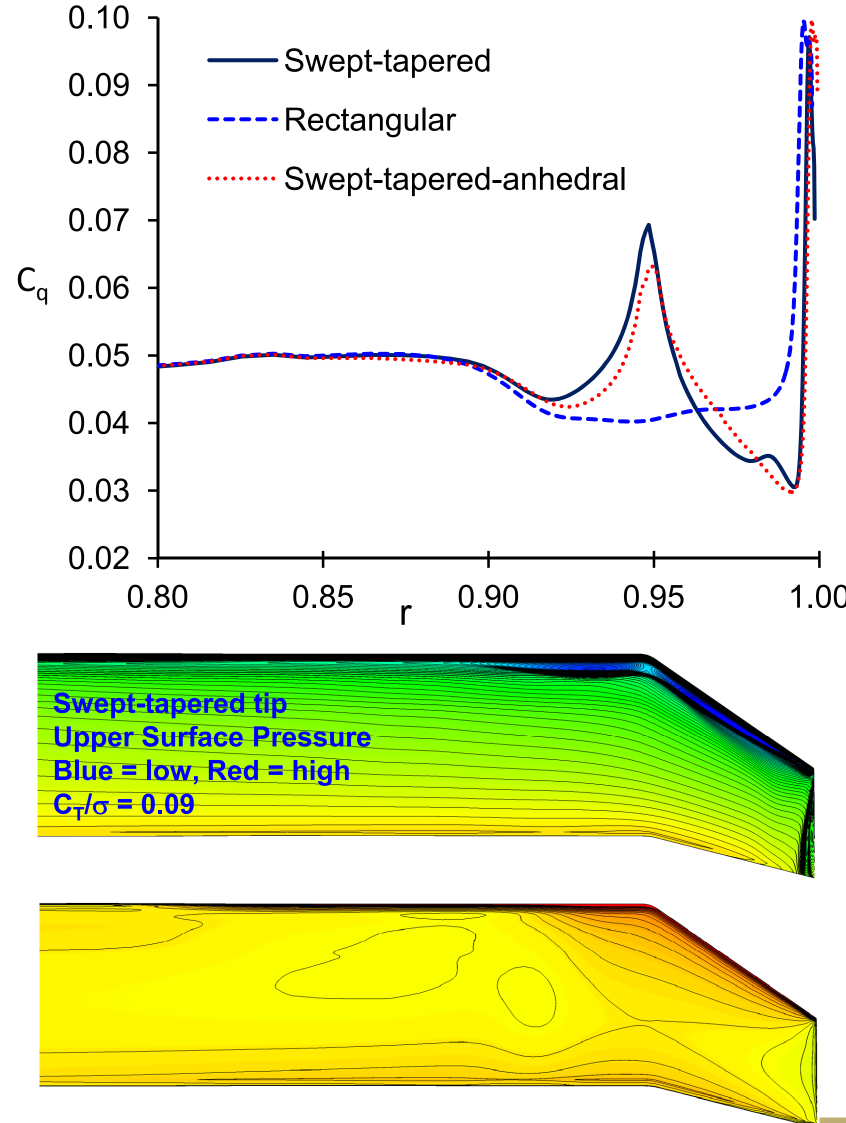
Facility effects expected to influence the flow-field and performance

Effect of Tip Shape Variation on Airloads

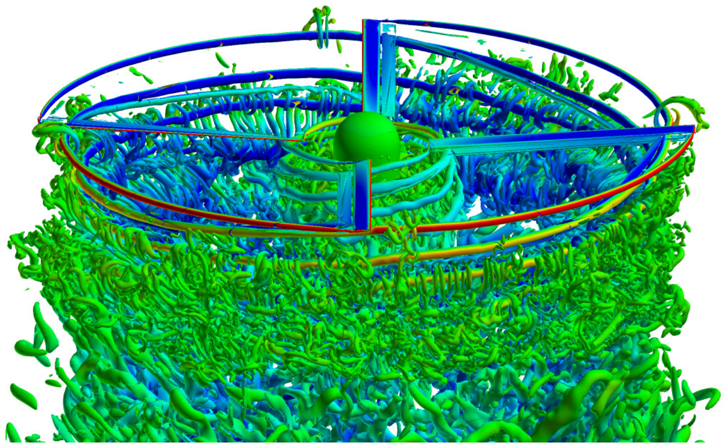
Section Thrust



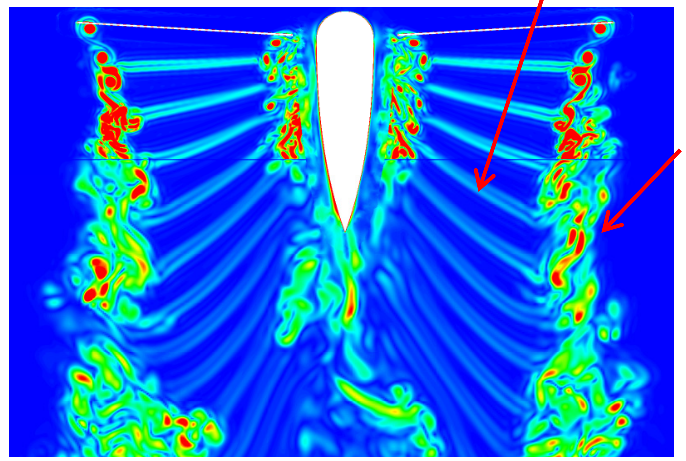
Section Torque



Wake Visualization



Inboard vortex sheets are preserved

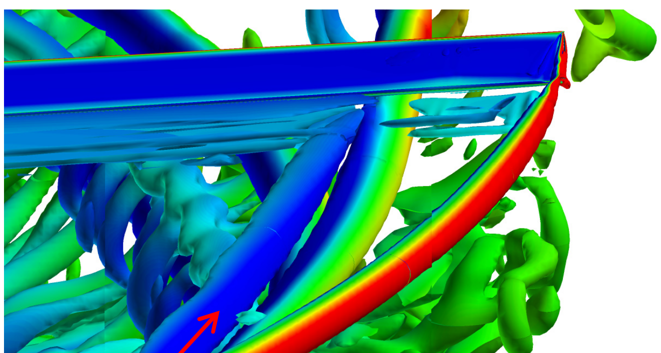


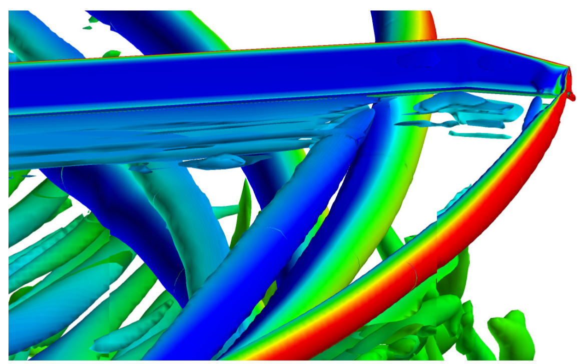
Tip vortices disintegrate

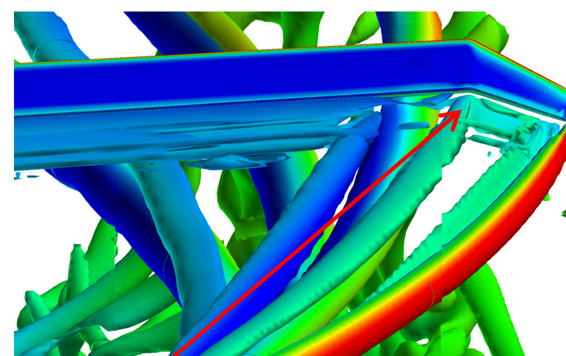
Rectangular

Swept-tapered

Swept-tapered-anhedral





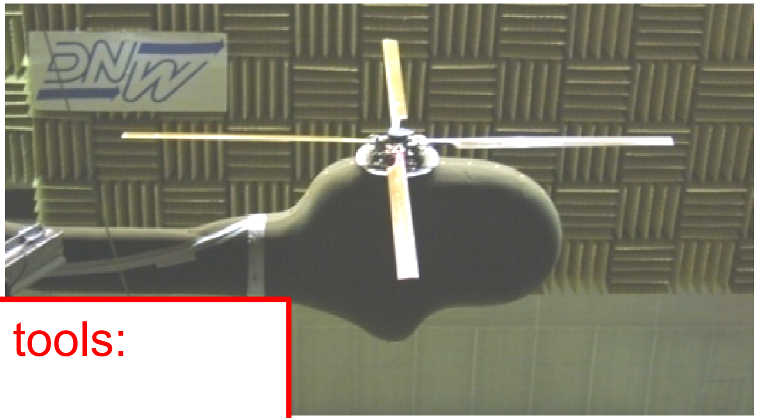


Inboard trailed vortex, induced by BVI

Additional vortex, induced by anhedral

CASE-II: HART II Interactional Aerodynamics

- **H**igher-harmonic **A**eroacoustics **R**otor **T**est
- 40% Mach-scaled Bo105 model rotor at the DNW wind tunnel
- Tests conducted by DLR
- **Baseline** conditions investigated here
  - Descending at
  - Shaft angle of
  - No higher-harm

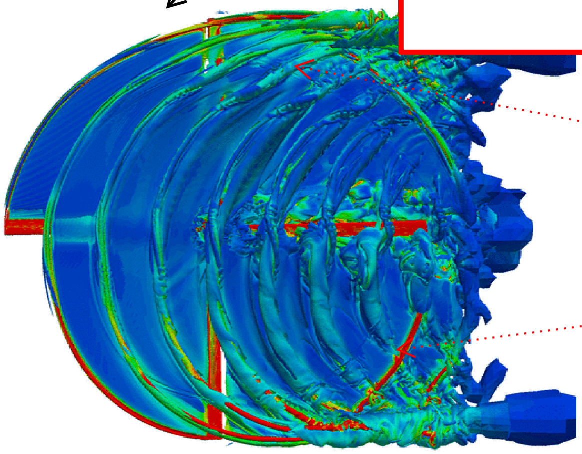


Challenges for the prediction tools:

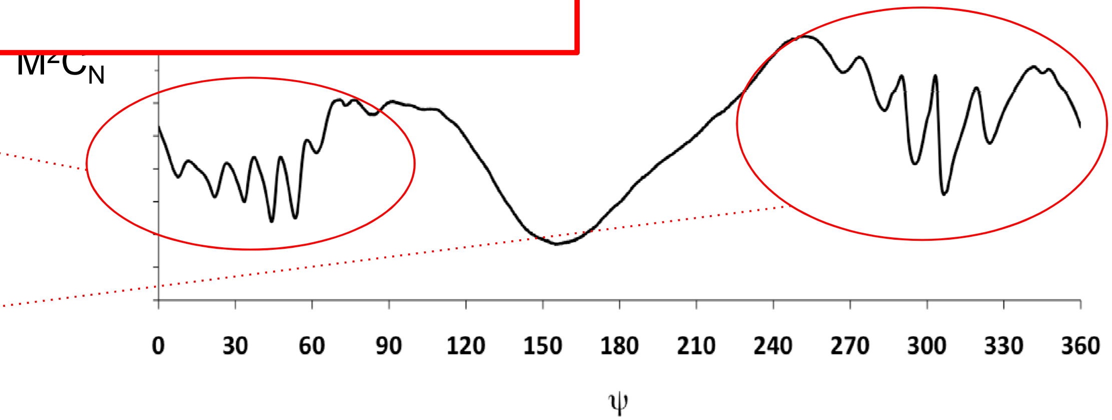
- **Wake vorticity (strength) & position**
- **BVI loading magnitude and phase**
- **BVI noise**

WIND

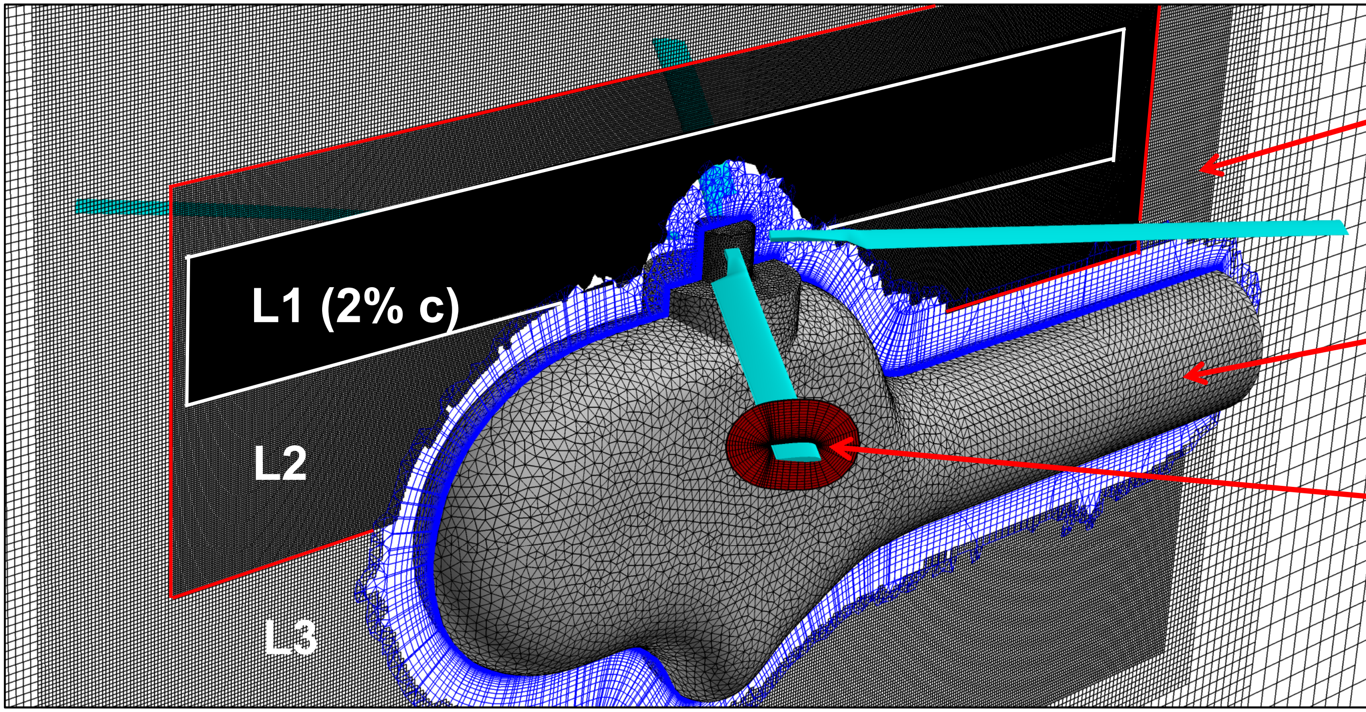
wake stays



teraction (BVI) Loads



Meshing Strategy



off-body Cartesian mesh (SAMARC)

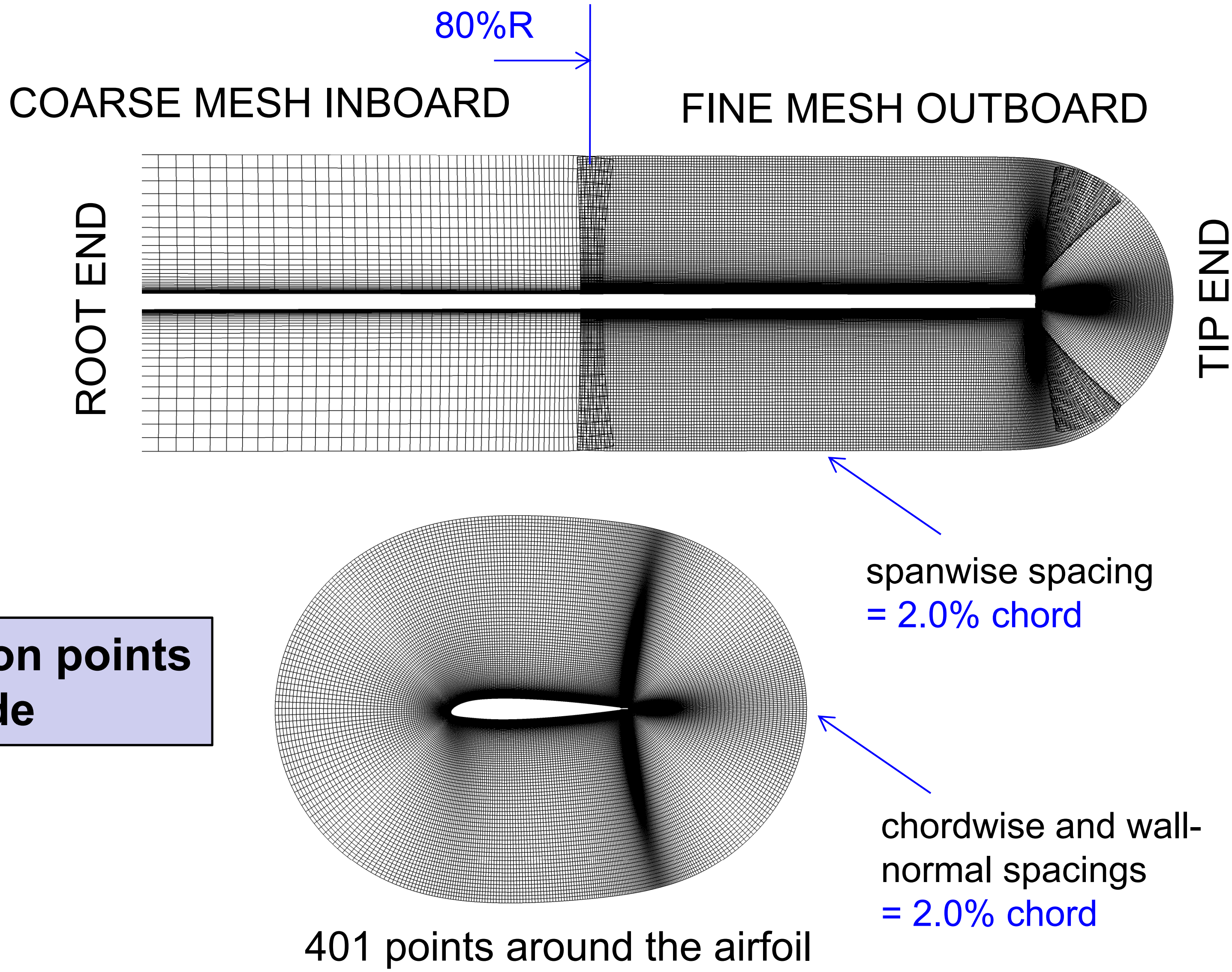
fuselage and hub unstructured mesh (NSU3D)

blade structured mesh (OVERFLOW) or unstructured mesh (NSU3D)

Rotor wake: 800 million points, static adaption (no AMR)

Fuselage and hub: 0.8 million points

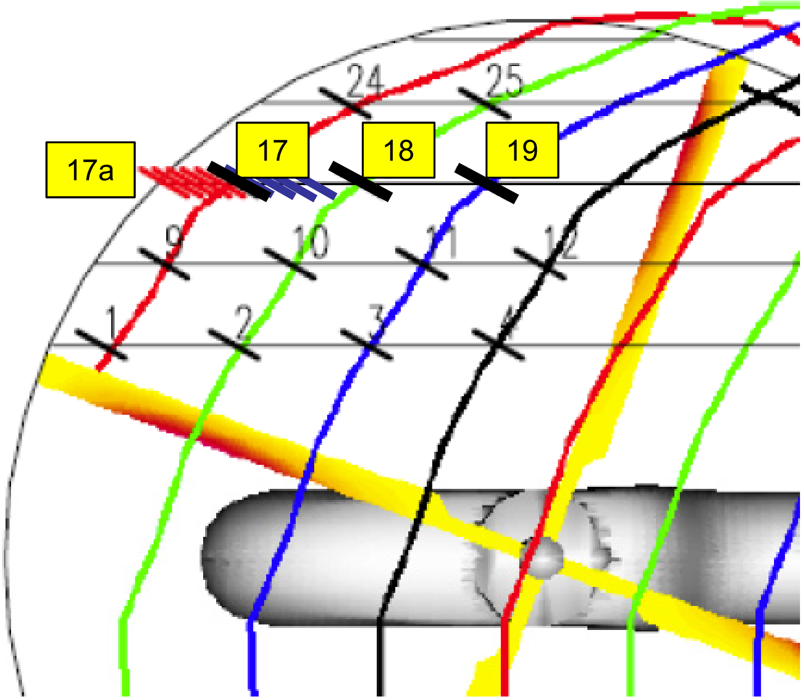
High Resolution OVERFLOW Blade Mesh



20 million points per blade

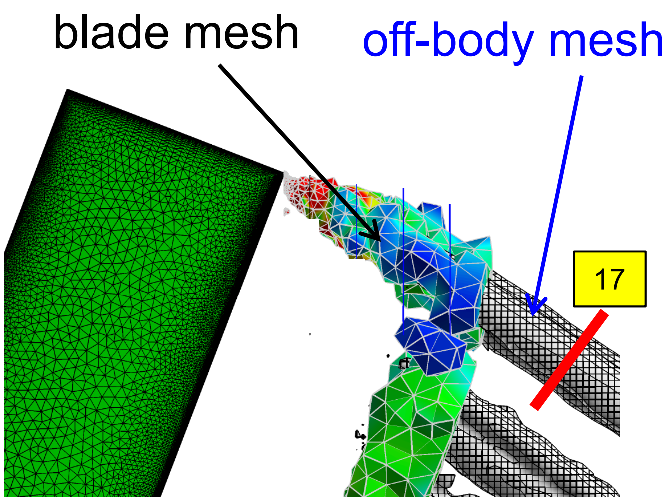
Tip-vortex Strength Prediction

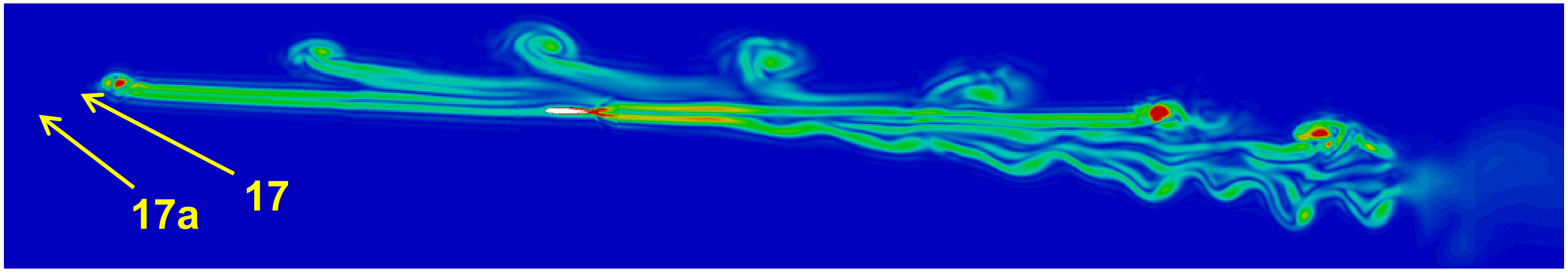
Position 17a: Wake age = 5.3 deg
Position 17: Wake age = 25.3 deg



Tip-vortex originates in the blade mesh and then it convects from the blade mesh to the off-body mesh at position 17.

Vortex diffusion that occurrs in the blade mesh cannot be recovered with mesh refinement in the off-body (wake) mesh

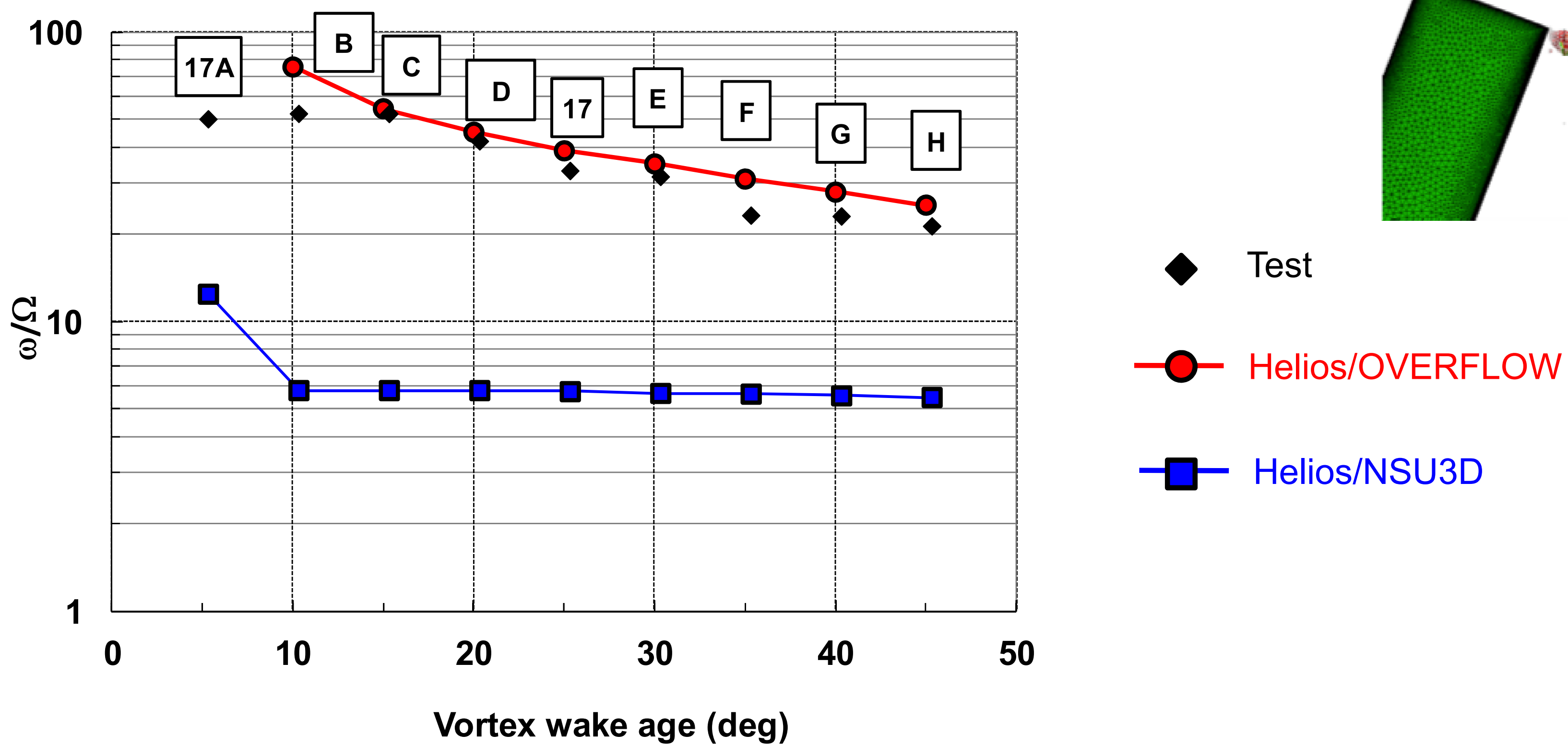


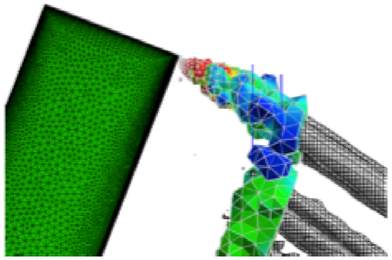


Tip-vortex Strength at Position 17

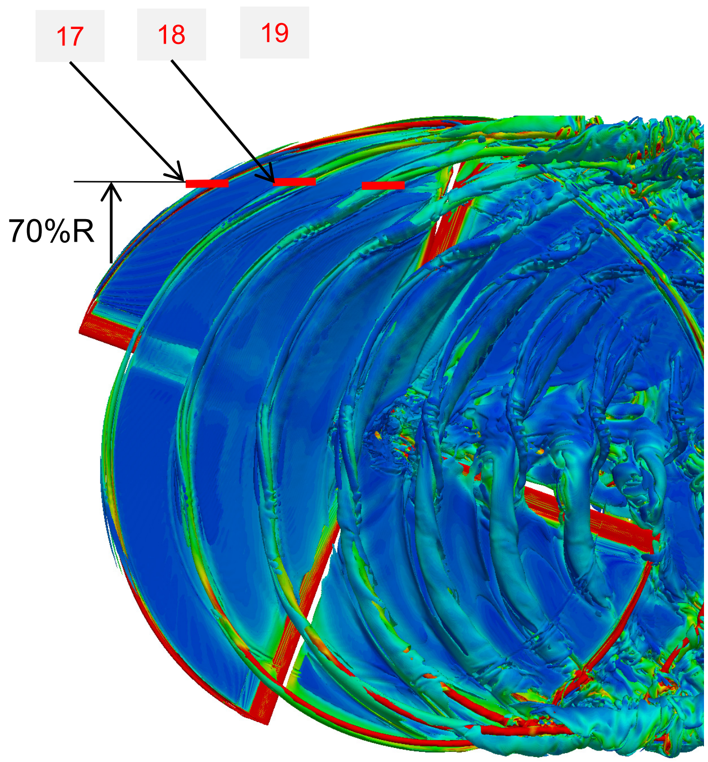
- **Helios/OVERFLOW: Fine blade mesh significantly improved the correlation**
- Helios/NSU3D: **Coarse blade mesh** caused rapid diffusion of the vortex

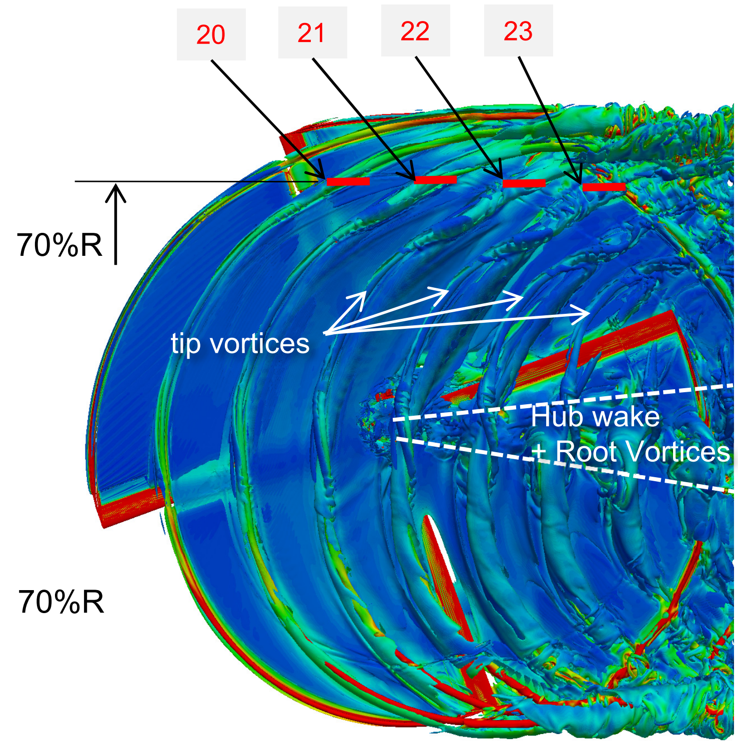
  Wake mesh refinement could not recover the lost strength

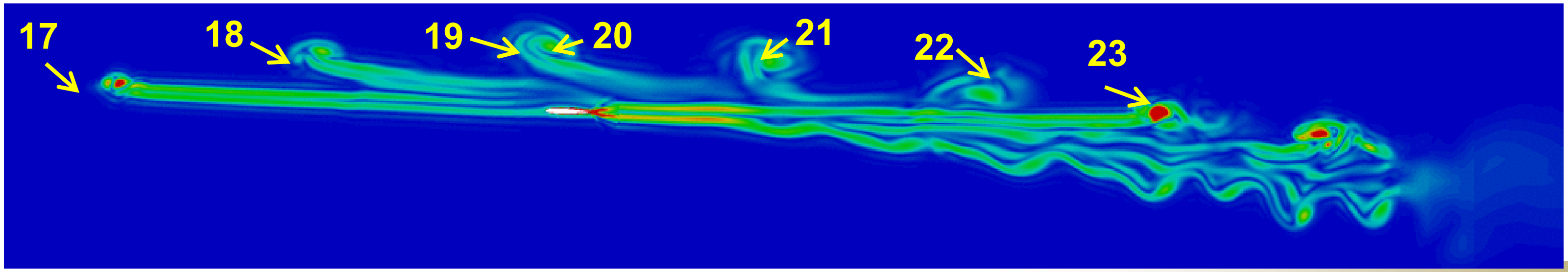




Tip-vortex Convection





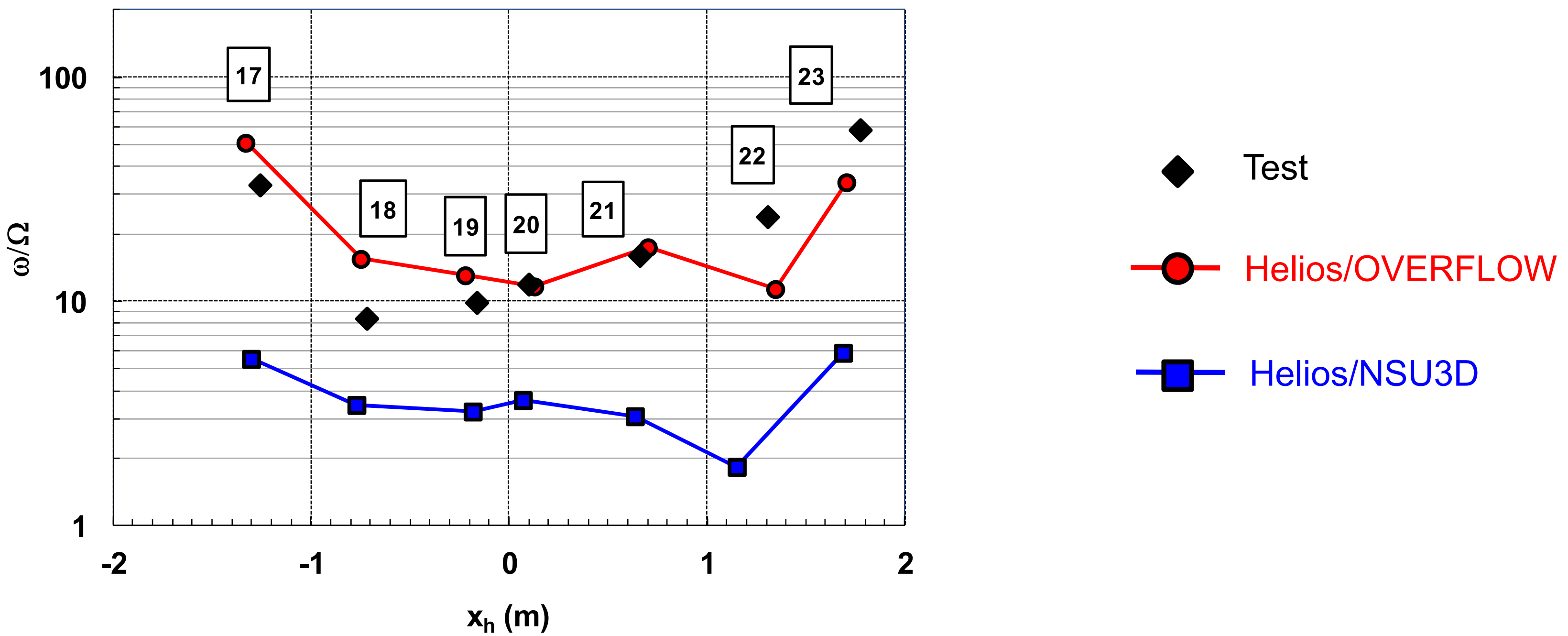


Convected Tip-vortex Strength Prediction

- **<u>Helios/OVERFLOW: Fine blade mesh significantly improved the correlation</u>**

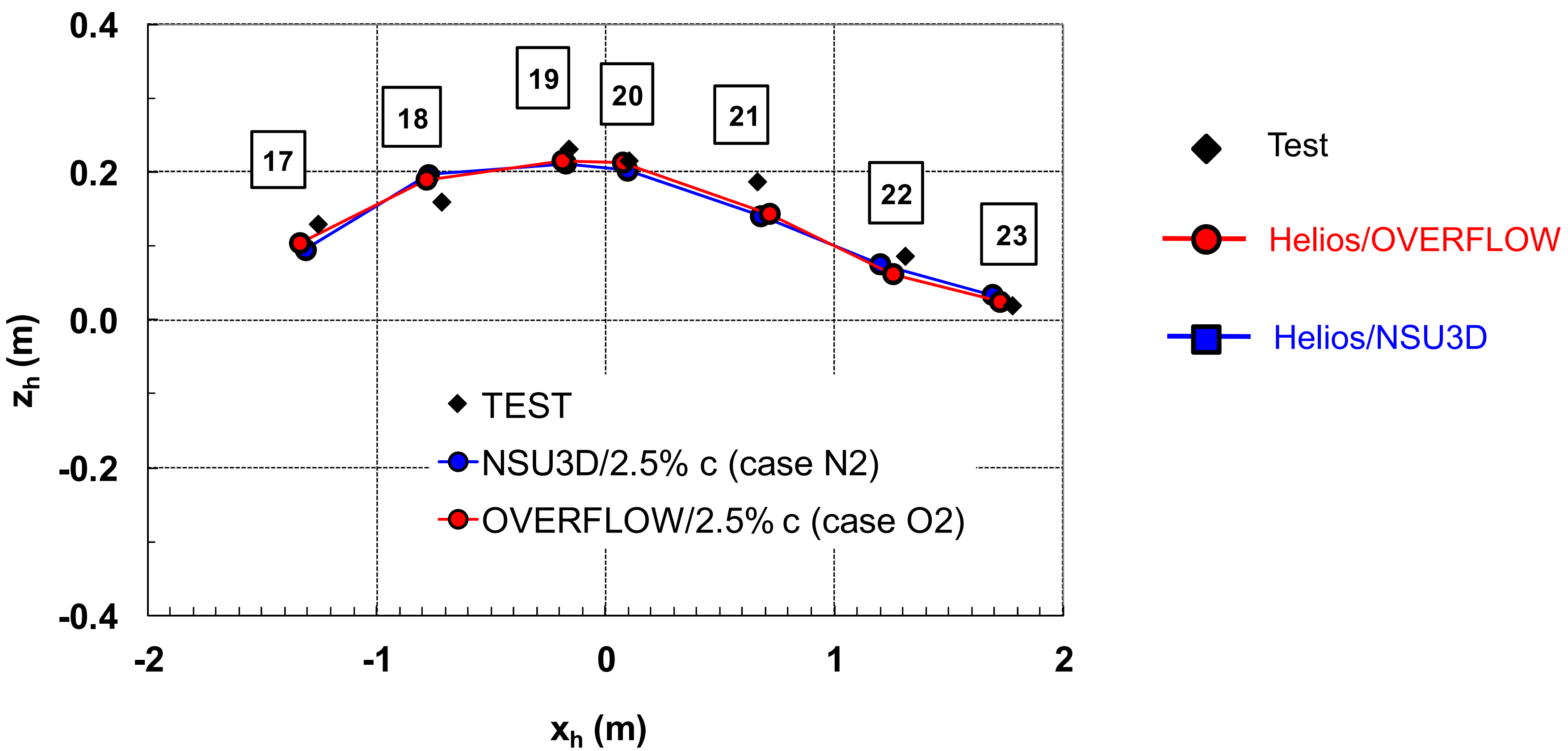
- **Helios/NSU3D: Coarse blade mesh caused rapid diffusion of the vortex**

  Wake mesh refinement could not recover the lost strength



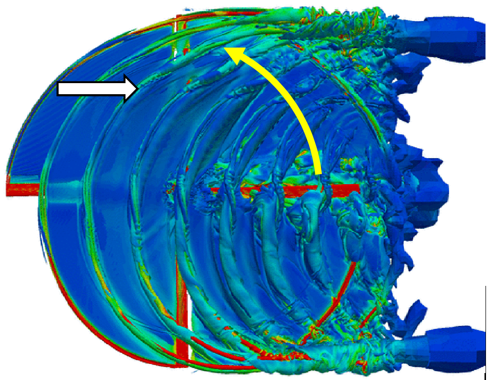
Convected Tip-vortex Position Prediction

- Vortex position is less sensitive to the vortex strength
- Good predictions were obtained with both

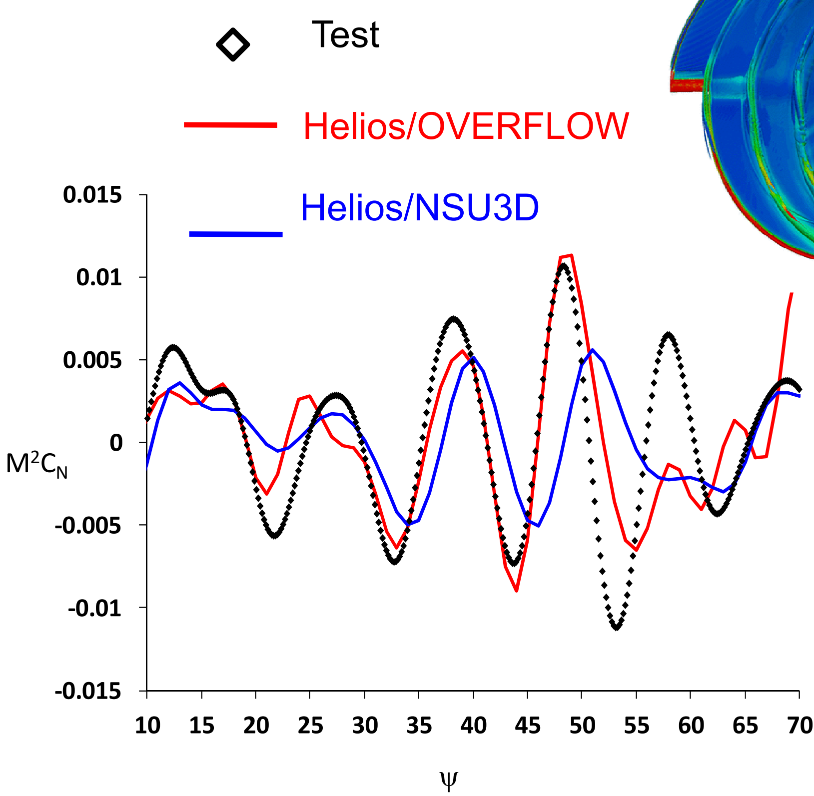


Advancing Side BVI Airloads Prediction

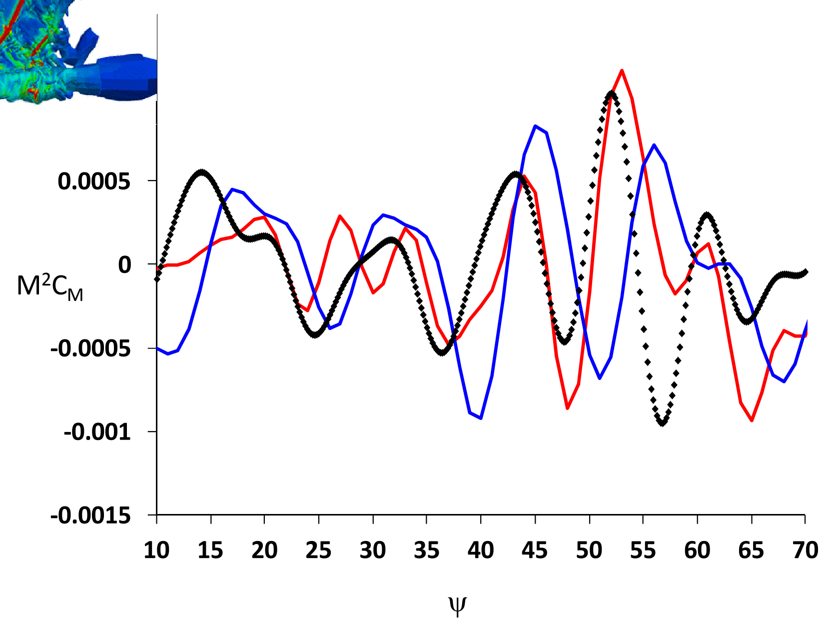
Helios/OVERFLOW: Fine blade mesh significantly improved the correlation in both the magnitude and phase



Higher harmonics loads (10 – 64/rev)



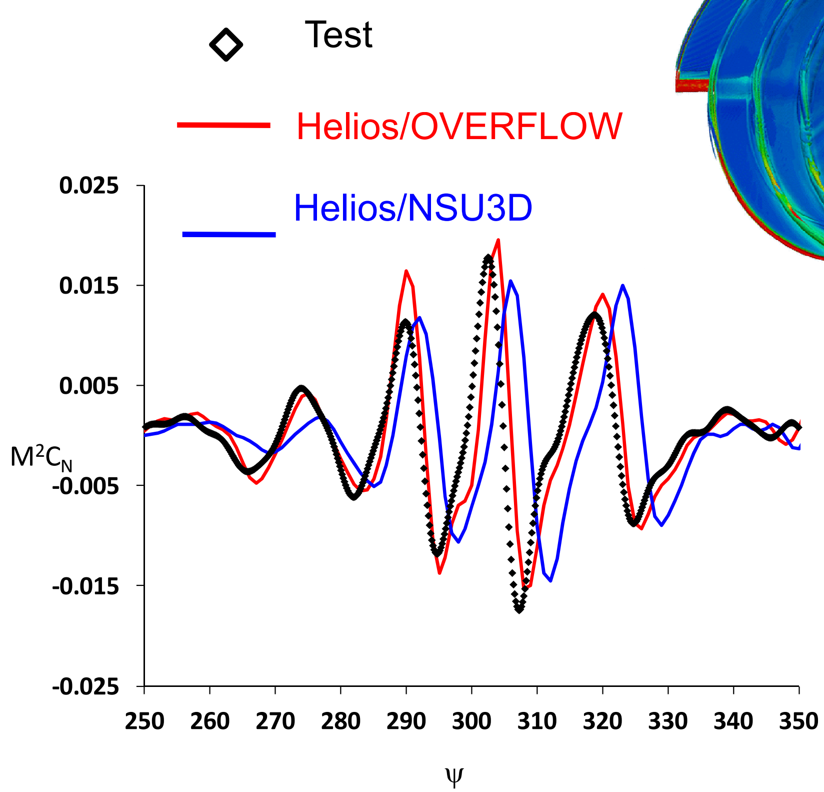
Section Normal Force

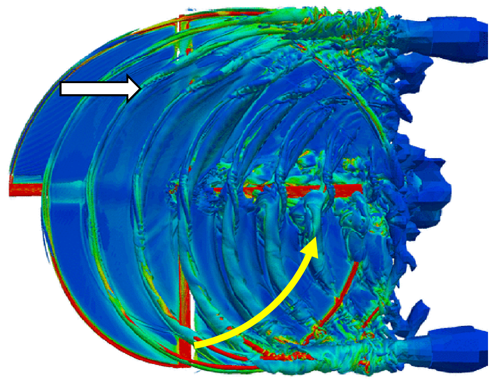


Section Pitching Moment

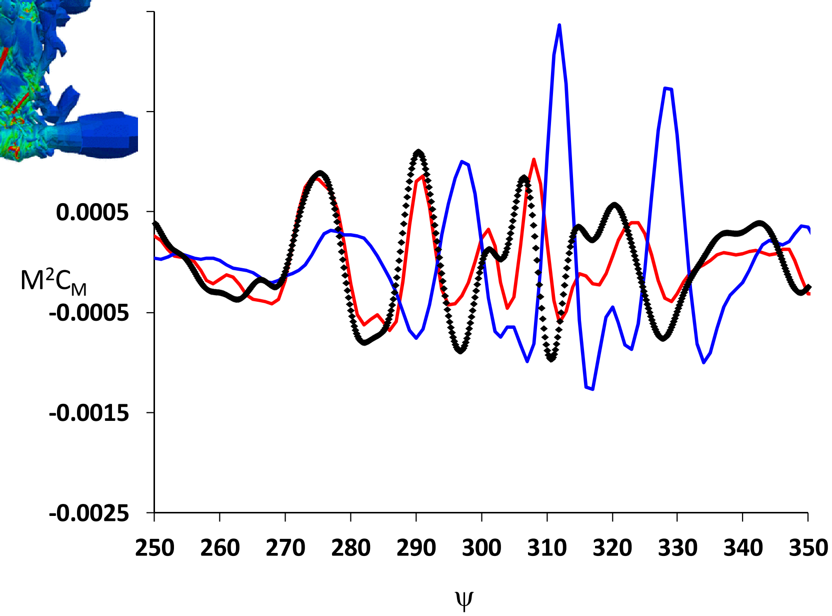
Retreating Side BVI Airloads Prediction

Helios/OVERFLOW: Fine blade mesh significantly improved the correlation in both the magnitude and phase





Higher harmonics loads (10 – 64/rev)



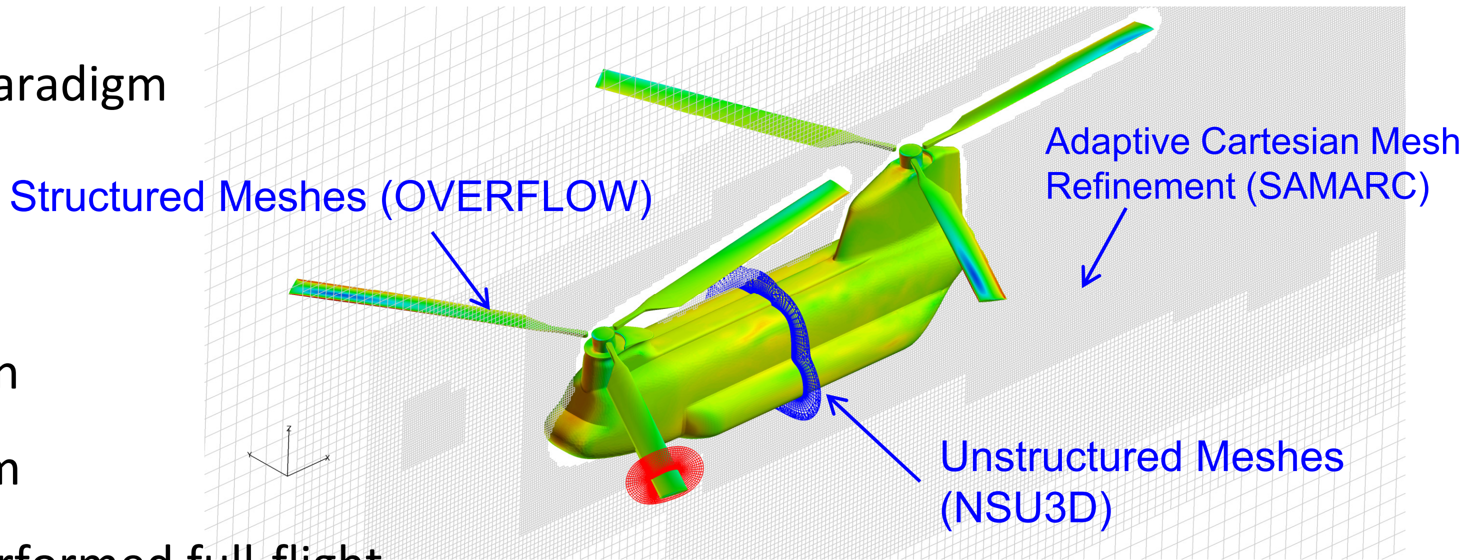
Section Normal Force

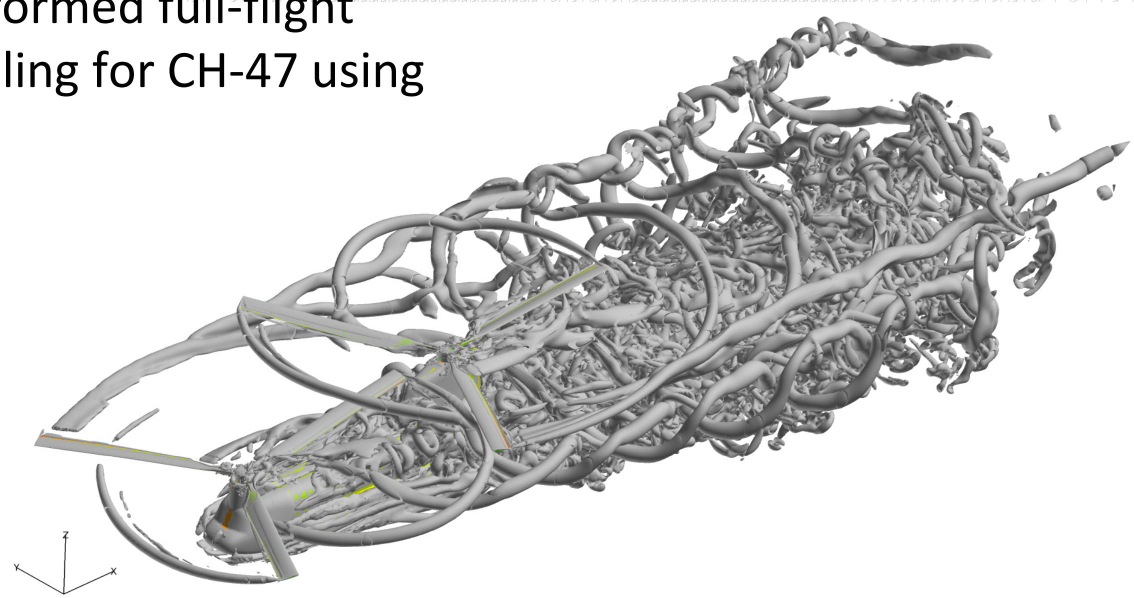
Section Pitching Moment

Examples of Complex Aircraft Configurations

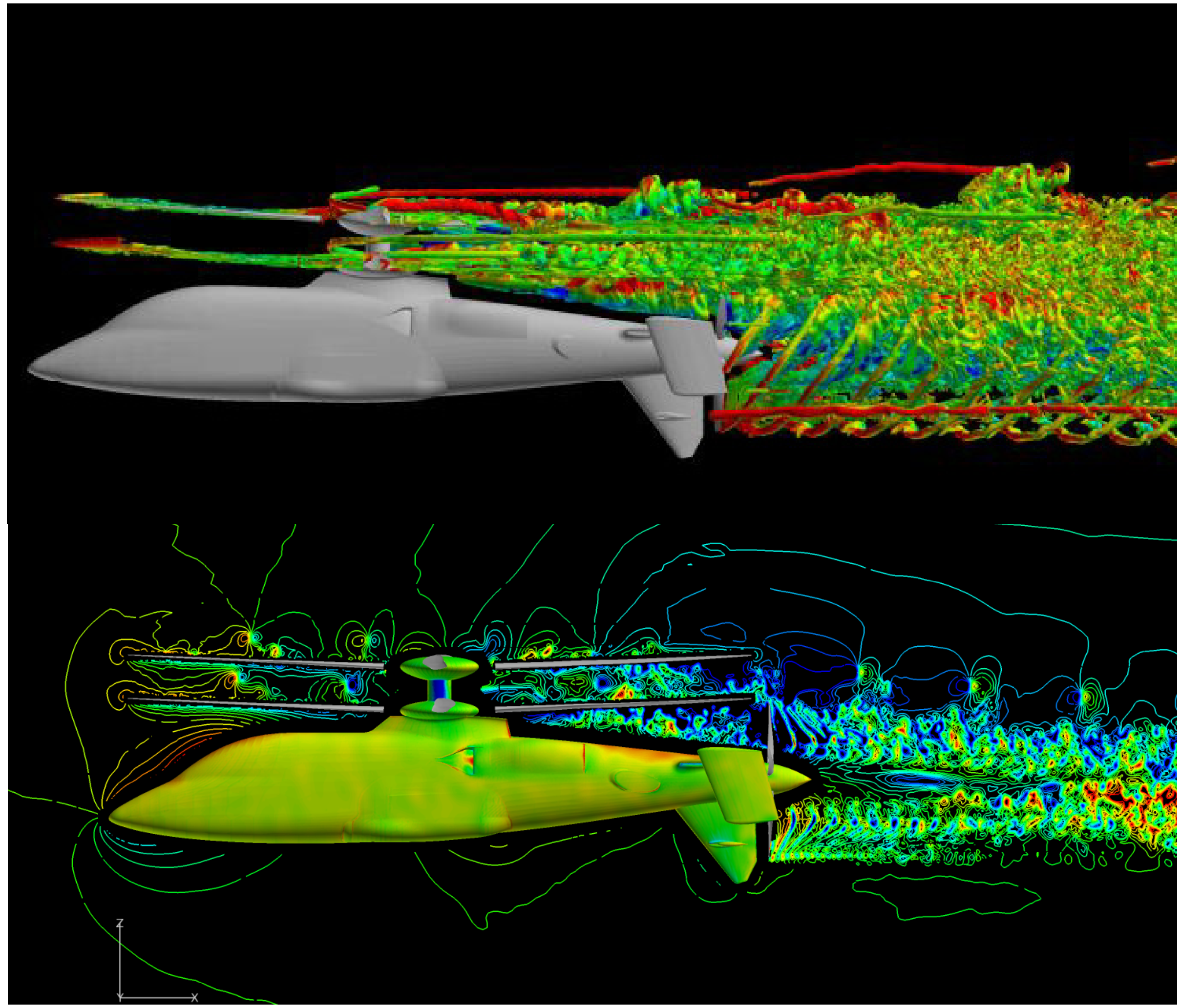
CH47 Interactional Aerodynamics

- Triple Mesh paradigm
- Dual-rotor
- CFD-CSD
- Mesh adaption
- Free-flight trim
- Boeing has performed full-flight envelope modeling for CH-47 using Helios





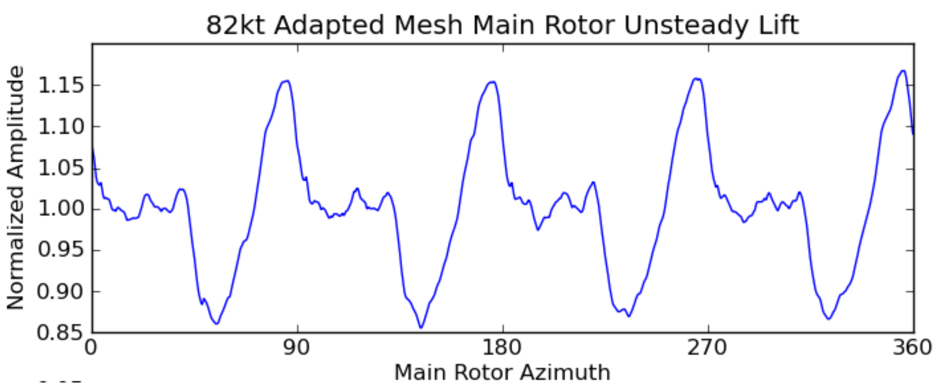
Sikorsky X-2 Helios Simulations

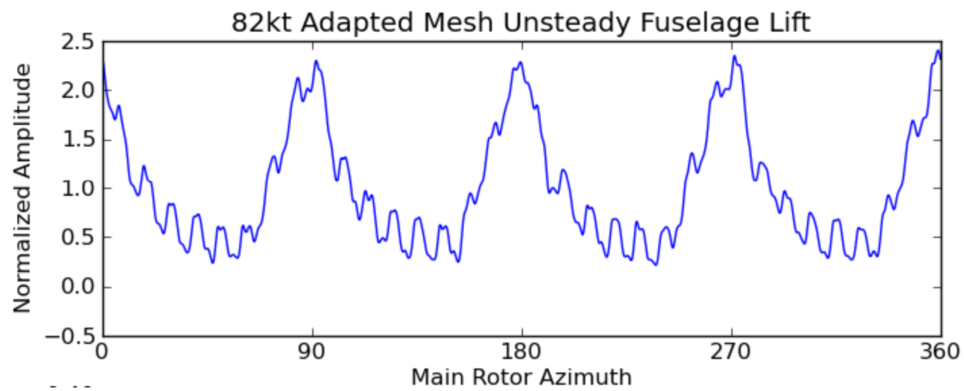


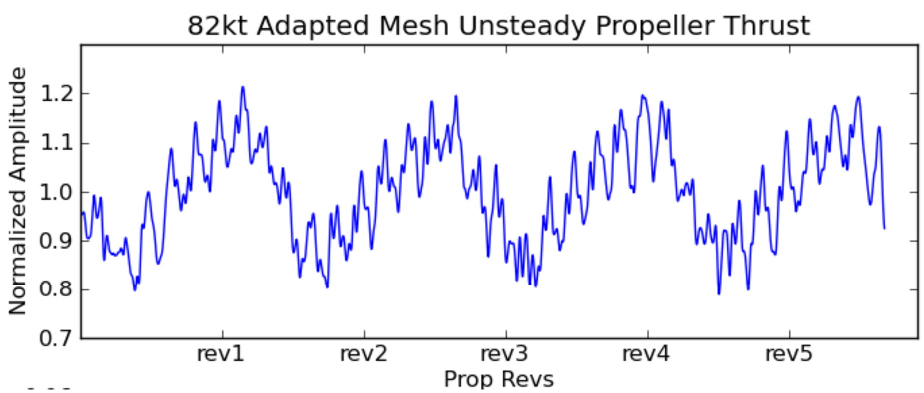
- Helios simulations provide high-fidelity modeling of the coaxial rotor system, the fuselage, and the propulsor

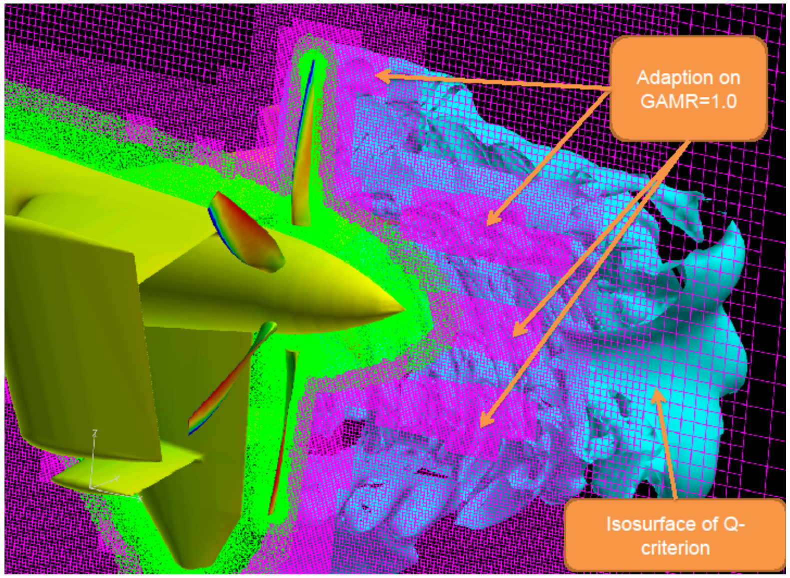
Alan Egolf, Ed Reed (Sikorsky)

Sikorsky X-2 Helios Simulations







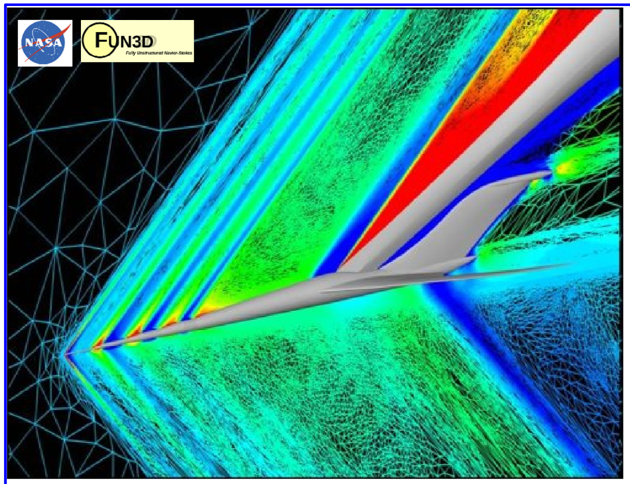


Helios simulations provide unique capabilities for modeling interactional aerodynamics effects between coaxial rotor system and propulsor

FUNCTION3D Modularization and Integration into Helios

Why FUN3D?

- Several key desirable features
  - Unstructured overset
  - Moving-body
  - Adjoint-based design optimization
  - Near-body grid adaption
  - Generalized fluid-structure interfaces (active rotors)
  - Turbulence and transition modeling



Mesh for Supersonic Boom Configuration After Adjoint-Based Adaptation

Courtesy: http://fun3d.larc.nasa.gov/

- Validated for a wide variety of rotorcraft problems
- Extensive user base
  - Effort spent in mesh generation, validation, developing know-hows…
- Continuously being developed and supported

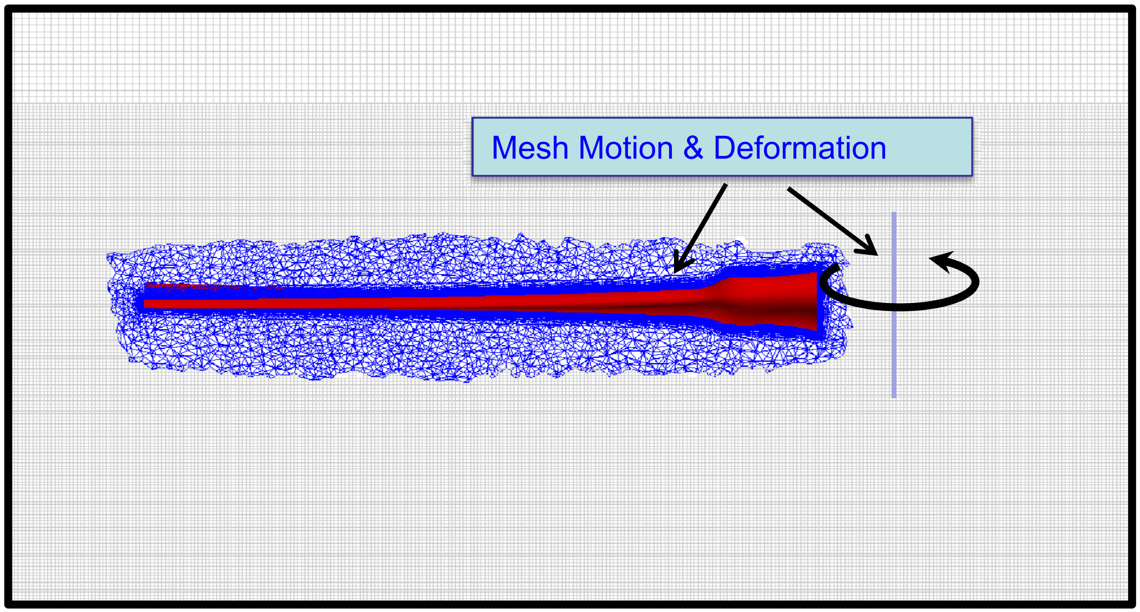
Modularized FUN3D

What is retained?

- ✓ Mesh Motion & Mesh Deformation
- ✓ Parallel grid partitioning

What is not?

- ✗ Off-body region
- ✗ CFD/CSD coupling



Helios modules used for:

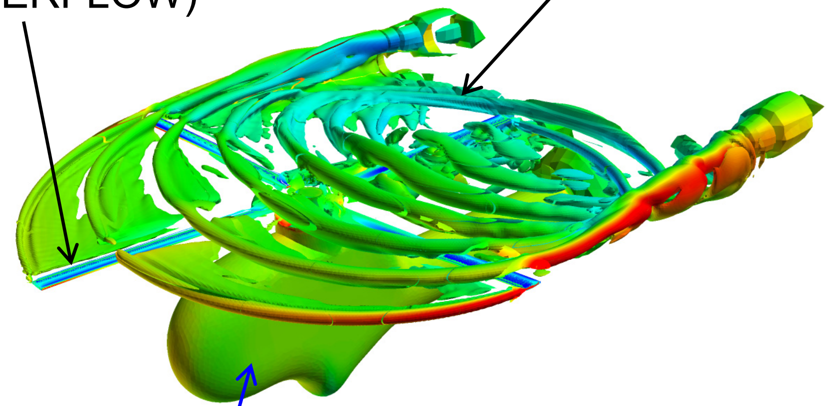
- Domain connectivity
- CFD/CSD coupling (RCAS/CAMRADII/…)
- Structured grids solution
- Adaptive Cartesian grids solution
- Co-visualization

….

Preliminary solutions…

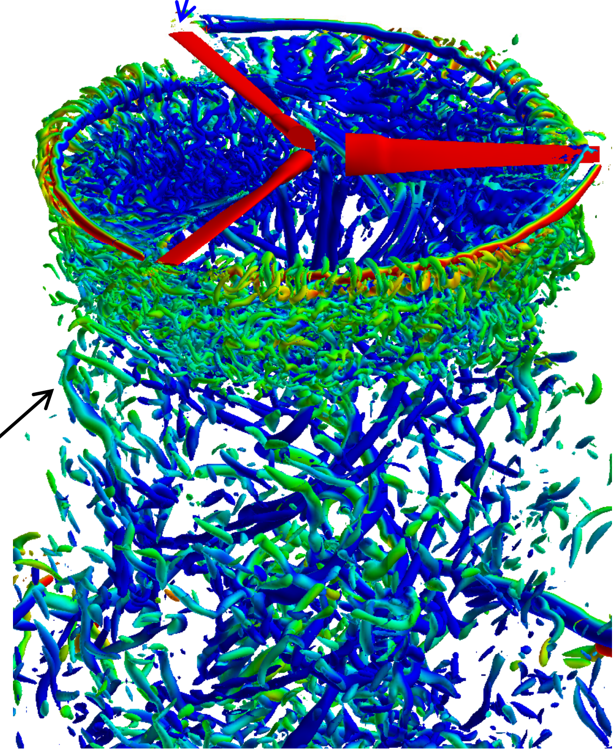
Structured Blade Mesh (OVERFLOW)

Adaptive Cartesian Mesh Refinement in the Wake (SAMARC)



Unstructured Fuselage Mesh (FUN3D)

Unstructured Blade Mesh (FUN3D)



Adaptive Cartesian Mesh Refinement in the wake (SAMARC)

Code Management Strategy

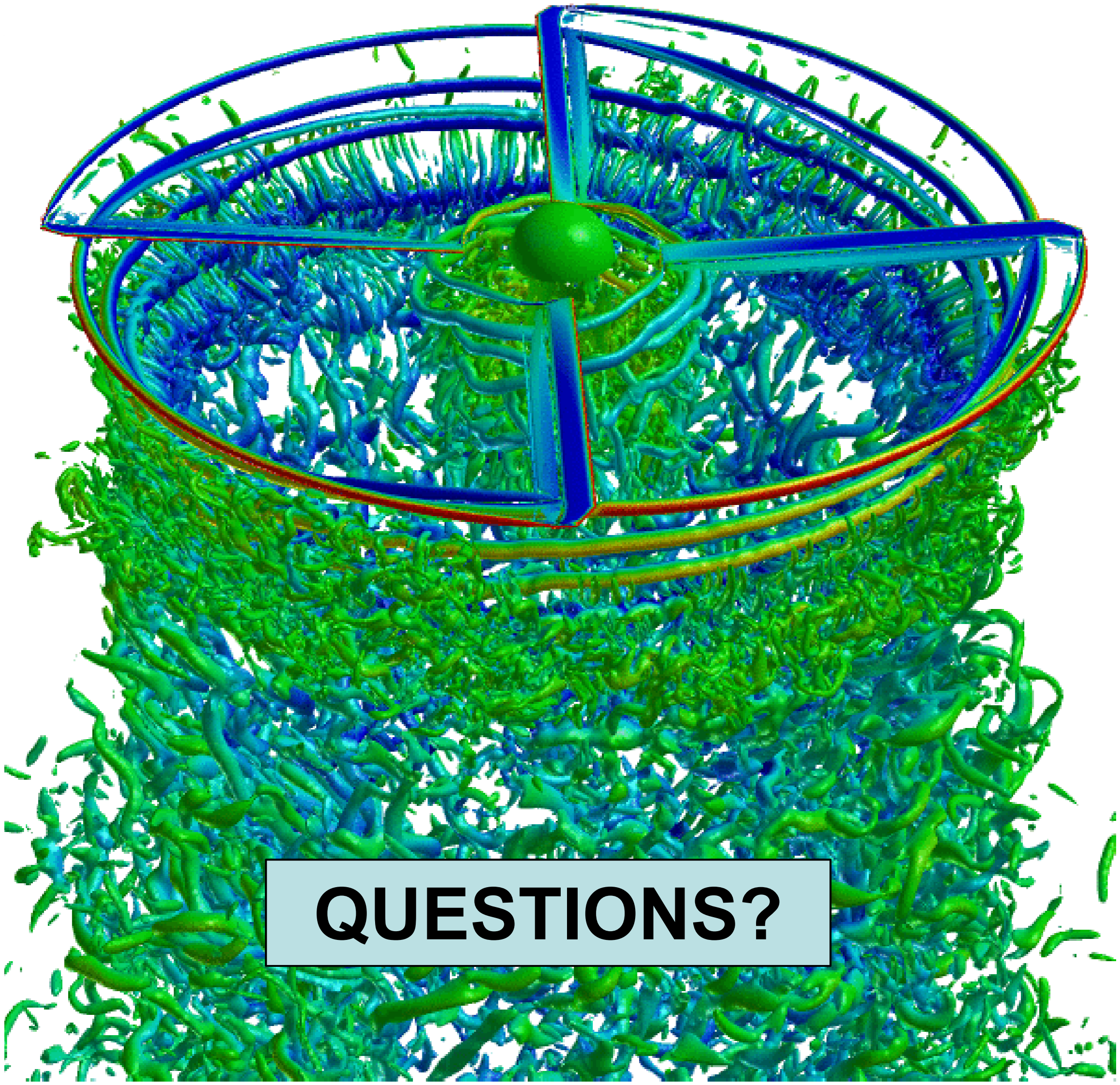
- FUN3D — Fully Unstructured Navier-Stokes
  - **A single, common source code repository**
    - `configure --enable-python` – compiles both
      1. the standalone executable (with DirtLib/SUGGAR)
      2. python module (uses Helios/PUNDIT)

    (Thanks to the Bob Biedron et al., NASA Langley.)

- Helios
  - **A common python interface for NSU3D, OVERFLOW, and FUN3D**

Summary and Concluding Remarks

- Helios's modular, python-based framework is flexible and extensible for incorporating new modules.
- The OVERFLOW code has been modularized into a Helios component as a near-body solver and validated on a variety of rotorcraft problems.
- Helios framework supports **multi-solver capability** (NSU3D, OVERFLOW, FUN3D, SAMARC)
- **This capability lends large flexibility to users and developers** (various combinations of grids and solvers) in solving the cutting-edge rotorcraft aeromechanics problems.
- **This capability facilitates Army/NASA/Industry/University collaborations**
  - Development and testing of new capabilities via customized versions of OVERFLOW, FUN3D, and other modules.


QUESTIONS?